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HIGH-SENSITIVITY MINIATURIZED
MAGNETIC SECTOR MASS SPECTROMETER
FOR THE ALSEP PROGRAM

FINAL REPORT
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I. INTRODUCTION

A. SCOPE AND SUMMARY

This document is the final report on the development, tests, results, and status of the Lunar ALSEP Mass Spectrometer (Figures 1-1 and 1-2) designed to measure the composition of the lunar atmosphere from a position on the lunar surface as part of an ALSEP array of scientific experiments. Included also is a discussion of the rationale for choosing a magnetic mass spectrometer for this program. The work was performed under NASA Contract No. NAS 9-7591. This project was conducted jointly between The University of Texas at Dallas and the Space Physics Division of MSC. The design and construction of the mass analyzer and associated electronics were the responsibility of The University of Texas at Dallas, while the structural and thermal designs and analyses were performed at MSC. The radiator plate, fiberglass housings, and base plate were fabricated at MSC. All functional and vacuum testing was accomplished at The University of Texas at Dallas. Environmental testing was performed at MSC. The Ground Support Equipment design was a joint program with the unit being constructed at MSC. The instrument developed is a small ($2\frac{1}{2}$ inch radius) magnetic deflection mass spectrometer with a dual filament ion source and three ion counting detector systems which simultaneously measure the concentrations of ambient atmospheric gas species in three different mass ranges. These ranges are 1 to 4 amu, 12 to 48 amu, and 40 to 160 amu. The mass spectrum is scanned by varying the ion accelerating voltage in a step-wise manner and counting the number of ions impinging on each detector per voltage step. The count magnitude determines the concentration of each constituent of the gas sample in the ion source, and the voltage step number identifies the

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Figure 1-1. Mass Spectrometer

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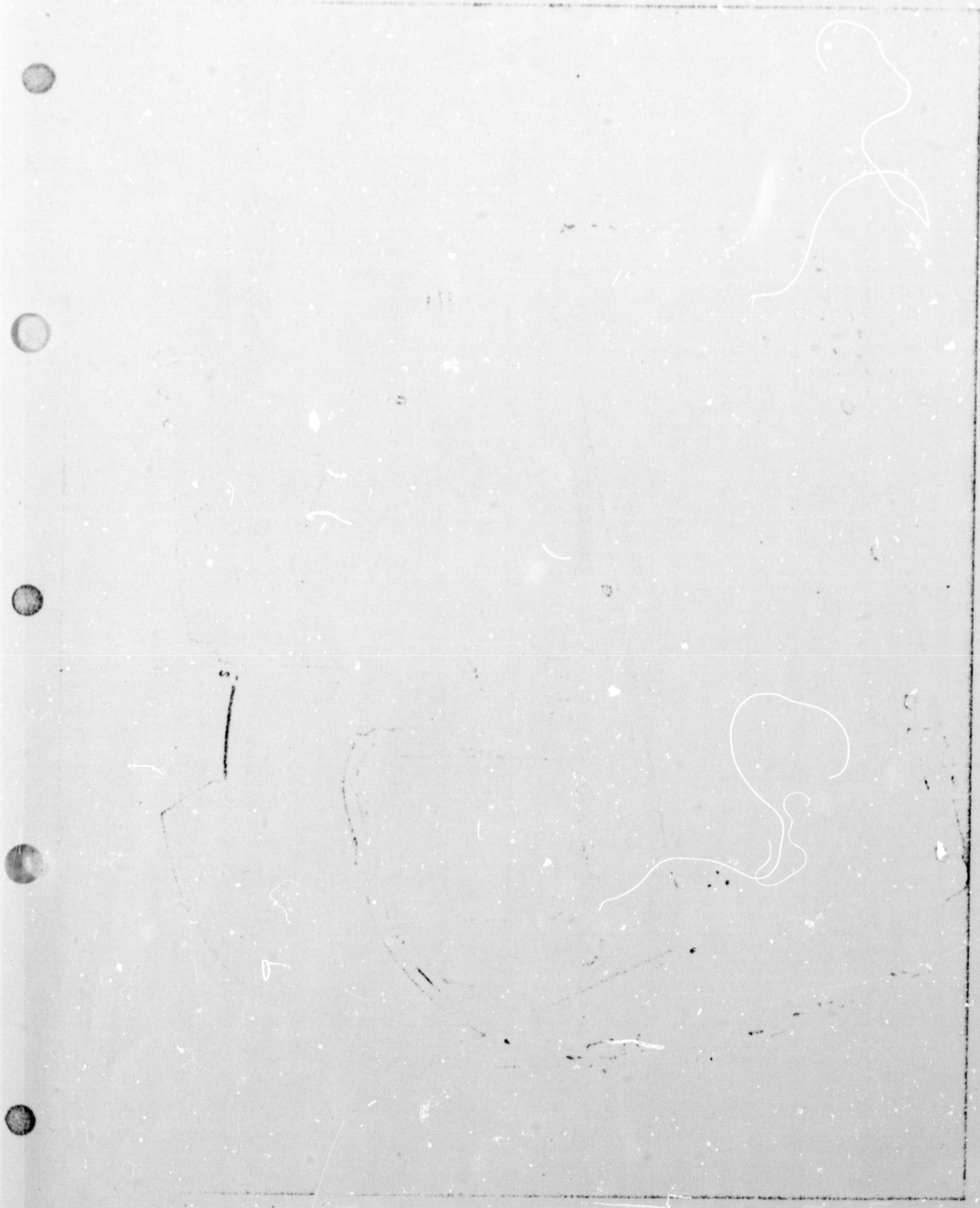


Figure 1-2. Mass Spectrometer Details

molecular weight of the species. With a dwell time of 1 second per voltage step, the instrument sensitivity is 10^{-14} torr.

A prototype model of the mass spectrometer has been packaged in a format suitable for use as an ALSEP experiment. The electronics are housed in a temperature controlled environment with a mirrored radiator plate on top and a thermal bag insulator surrounding the other five sides. Figure 1-1 shows an exterior view of the prototype package. The electronics package is mounted above the base plate which bisects the package. The magnetic analyzer is below the base plate, Figure 1-2 (bottom view) and contains the ion source, magnet, electron multipliers, and analyzer tube, and ALSEP cable reel. A thermal model and the prototype model underwent thermal vacuum tests, the results being included herein. A structural model was built and both it and the prototype were subjected to qual level vibration tests. The test results show that structurally and thermally the mass spectrometer experiment will survive the ALSEP environment.

B. SCIENTIFIC OBJECTIVES OF EXPERIMENT

1. Primary Objectives

A primary scientific objective of the Mass Spectrometer Experiment is to obtain data on the composition of the lunar ambient atmosphere in the mass range 1 to 160 amu at the lunar surface. A second goal is the detection of transient changes in composition due to venting of gases from the surface, or from man made sources.

There are several areas of lunar study in which data from a mass spectrometer experiment are applicable. These measurements are important in investigating the suggestion that noble gases, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, sulphur dioxide and water vapor may be released by lunar volcanism and from rocks and magma. Argon would be a particularly

significant gas to study because of its relationship to the K-Ar dating process. Also its isotopic composition would be of interest, as the different isotopes have different origins or production mechanisms. Ar^{40} is formed by the decay of K^{40} . Ar^{36} and Ar^{38} may be spallation products of cosmic ray interactions with surface materials. Perhaps the mechanisms or release of gases from the surface, e.g. solar wind bombardment, can be affirmed after determining which of the effluent gases comprise the lunar atmosphere. Likewise, data on released gases will certainly afford some knowledge of the chemical processes underlying the lunar surface. Location of areas of released gases are related to the selenological structures in these areas. By triangulation techniques mass spectrometers could be used to locate areas of active volcanism on the moon if three or more instruments carried on successive missions were operating simultaneously on the lunar surface.

The firing of the ascent rocket of a lunar landing module is a good example of a known point source of gas on the lunar surface. The rate of spreading of this gas cloud around the moon can be studied by mass spectrometers placed on the surface during a previous landing and diffusion rates for the various gases calculated. Also the escape rates of gases of various molecular weight can be determined. Some of the gases from the rocket will be absorbed on the lunar surface materials, so the out-gassing rates of these absorbed gases can be measured. From this information the amount of contamination of the lunar atmosphere, due to both past and future firings of rocket motors near the surface, could be estimated. Finally, mass spectrometers will provide the means for determining the natural distributions of gases in the lunar atmosphere. This information

is essential if the sources, sinks, and transport of these gases are to be understood. Since the lunar atmosphere is a classical example of an exosphere, its global structure can be used to test theories on exospheric transport, which is an important process in the terrestrial atmosphere.

It has been shown (Hodges and Johnson, 1968) that light gases with negligible production and loss rates tend to be distributed at the lunar surface as the inverse $5/2$ power of temperature, while heavier gases are influenced by rotation of the moon. Neon falls into the former category, and its concentration on the dark side should be about 32 times that on the sunlit side. Argon, being heavier, is expected to be noticeably influenced by rotation of the moon, having slightly less diurnal variation than neon, and a longitudinal shift of its maximum toward sunrise, resulting in a concentration at sunrise that is about 2 times that at sunset.

Other atmospheric gases are not as amenable to analytic analysis, but their distributions are nonetheless important. Hydrogen and helium, which are thought to originate mainly through neutralization of solar wind ions on the lunar surface, are produced mainly on the sunlit surface, escape easily, and thus are not expected to be concentrated excessively on the dark side. The accretion rates can be calculated assuming a direct impingement of the solar wind on the lunar surface (Hinton and Tausch, 1964). Both these assumptions and the processes of accumulation and escape of these gases can be checked with the mass spectrometer data.

Water vapor, krypton, and xenon probably exist in the lunar atmosphere, but not on the dark side, nor near the poles, where the surface temperature is thought to be below 100°K , and absorption must remove every particle that comes in contact with the surface. Gases absorbed

in continuously shadowed regions near the poles are unlikely to reenter the atmosphere, but at lower latitudes the rotation of the moon transports absorbed gases into sunlight where they are released into the atmosphere. Since surface heating occurs rapidly, this release probably occurs entirely within a few degrees longitude from the sunrise terminator, creating a pocket of gas which would be detected by a mass spectrometer on the surface with each rotation of the moon.

2. Significance of Experiment

Study of the composition and distribution of gases in the lunar atmosphere is important to two current problems. First is the understanding of the origin of the lunar atmosphere. Light gases, such as hydrogen, helium, and neon probably originate from neutralization of solar wind ions at the surface of the moon, while Ar^{40} is most likely due to radioactive decay of K^{40} . Ar^{36} and Ar^{38} may be expected as spallation products of cosmic ray interactions with surface materials. Molecular gases, such as carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, sulphur dioxide, and water vapor may be produced by lunar volcanism.

The second problem is related to transport processes in planetary exospheres. The exosphere of the earth, and that of almost any other planet, is bounded by a dense atmosphere in which hydrodynamic wind systems complicate the problem of specifying appropriate boundary conditions for exospheric transport. This contrasts sharply with the situation in the lunar atmosphere, which is entirely a classical exosphere with its base the surface of the moon. The lunar exosphere should be amenable to accurate, analytical study. Experimental determination of the global distributions of lunar gases can provide a reasonable check on theory, giving confidence to the application

of theoretical techniques to transport problems in the terrestrial exosphere.

3. Anticipated Results

The gases thought to be dominant in the lunar atmosphere are hydrogen, helium, neon, and argon, with the abundance of neon exceeding the others by about an order of magnitude. Other gases, and their sources, are speculative at this time, but composition measurements should lead to better understanding of the mechanisms which release gases from the lunar surface. In addition, transient concentrations of volcanic gases, if present, will aid in understanding lunar volcanism.

It is also expected that much will be learned regarding exospheric transport. Neon and argon are the preferred gases for this study because their distributions are not expected to be affected by escape or surface absorption (Hodges and Johnson, 1968). Neon is particularly interesting, since its distribution at the surface is expected to vary as the inverse $5/2$ power of surface temperature, resulting in the concentration on the dark side being about 32 times that on the sunlit side. The distribution of argon is expected to be noticeably influenced by the rotation of the moon, resulting in its abundances over the sunrise terminator being about twice that over sunset. Measurement of the distributions of these two gases with rotation of the moon will be of great value in testing and improving current theoretical techniques for analysis of exospheric transport processes.

4. Relevance to Future Effort

With each manned lunar expedition, the contamination of the tenuous, native atmosphere of the moon will become greater, and the significance of study of the lunar atmosphere to planetology will be lessened. Therefore, it is

important that an attempt be made to measure the composition and distribution of gases at the lunar surface on the earliest possible Apollo flight, and that similar or improved instrumentation be carried on future flights as well.

5. Brief History of Related Work

The physical and chemical properties of the atmospheres of the planets (and the moon) other than the earth are not well known, but enough is known to make it clear that there are interesting and systematic distinctions among them. Some of these are apparently indicative of the differing conditions under which the individual planets were formed, whereas others result from the divergent evolutionary paths for the different planetary atmospheres.

To date no atmosphere has been detected on the moon. The most critical test for a neutral atmosphere has been the occultation of stars by the moon; while this test is not very accurate, it has given an upper limit of 10^{-6} atmospheres. A much more critical test exists for electrons by occultation of radio stars or, better yet, spacecraft transmitters that are synchronized to ground transmitters. Occultation of radio stars has given a limit of about 10 electrons (and ions)/cm³. Occultation of spacecraft has indicated a slight gradient in concentration, with concentrations increasing with increasing distance from the lunar surface, an observation that is not well understood. A spacecraft orbiting the moon has observed the lack of a shock wave in the solar wind (Colburn et al., 1967), and this has been explained in terms of the solar wind impinging directly upon the moon (Johnson and Mudgley, 1968). Under these conditions, an ion formed from an ambient lunar atmosphere will be swept away promptly by the electric field associated with the solar wind, the acceleration time varying from about 10 sec for hydrogen to 10^3 sec for xenon. The degree of ionization will

be approximately the ratio of this acceleration time to the lifetime of the atom or molecule against ionization by solar radiation, which is about 10^7 sec. The upper limit on ambient atmospheric gases is therefore about 10^{-10} torr for hydrogen and less for heavier gases (10^{-12} torr for xenon).

There is some evidence indicating the release of gases, at least sporadically, from the lunar interior. Middlehurst (1967) has summarized the visual evidence for color changes at specific locations on the lunar surface. These are interpreted as luminescence associated with gas release. About 400 cases have been observed, with maximum activity in the vicinity of Aristarchus. The best presumption is probably that the composition of the released gases is similar to volcanic gas on earth.

Although not much gas can be expected on the moon, any identifiable gases of internal origin will be important from a geochemical viewpoint. They should provide clues to the internal composition of the moon, and hence possibly to its origin. The impact of the solar wind on the moon provides a source of about 3×10^8 hydrogen atoms/cm²-s, and lesser amount of heavier atoms - perhaps 3×10^7 helium atoms/cm²-s, 1.5×10^5 neon atoms/cm²-s, and 2×10^3 argon atoms/cm²-s. The most plentiful gas of solar origin on the moon should be neon, for which a daytime partial pressure of about 10^{-11} torr might be expected. The partial pressure of hydrogen, helium, and argon should be expected to be about 10^{-13} torr. The more plentiful gases in the solar wind will escape more rapidly than neon due to thermal escape, and the heavier gases will be less abundant than neon because of their lesser solar abundances.

C. RATIONALE FOR TYPE OF MASS SPECTROMETER STUDIED

A magnetic deflection sector field type of mass spectrometer was selected for development into a package suitable for measuring the composition of the lunar atmosphere as part of an ALSEP array of scientific instruments under a contract NAS9-7591, received from MSC in November, 1967. This instrument has also been proposed in "Gas Analyzer for the Lunar Atmosphere-GALA", proposal No. 6969, dated October 25, 1969 (from UTD, John H. Hoffman, PI) for future ALSEP missions. The main reason for selecting a magnetic deflection instrument is its inherent simplicity and stability and its long-proven record in laboratory usage throughout the world for isotopic abundance studies, nuclidic mass determinations, geochronology studies, hydrocarbon analyses and many others. Upwards of 30 magnetic instruments have been flown successfully in rockets to study the composition of the earth's upper atmosphere and ionosphere and five satellites have carried such instruments (the PI of the above referenced proposal has prepared and flown 14 rocket instruments and one satellite Mass Spectrometer with two additional satellite instruments under construction).

The magnetic deflection spectrometer is inherently simple in its design and operation. A sweep voltage is applied to the ion source region which accelerates ions into a collimated beam that enters normally into a magnetic field which separates the ions into different trajectories as a function of their mass. The magnetic field is derived from a small high-flux permanent magnet with low leakage. Being a permanent magnet, no electrical power is consumed in its function. The magnetic field is stable, as are the power supplies which drive the Mass Spectrometer sweep voltage and detector systems making the entire system stability high. Because the magnet design produces little stray field, the flux around the instru-

ment, i.e., 12 inches from the magnetic shield encompassing the instrument, is of the order of 1000 gamma. No RF fields are used. The electronics, therefore, are straightforward and require a minimum of shielding.

The mass resolution of the magnetic deflection mass spectrometer is adequate to meet the requirements for lunar atmospheric studies. The resolution is such that at mass 135 less than 1 percent contribution occurs from either adjacent mass number peak. At mass 39 there is less than 1 part in 300 contribution from the mass 40 peak (Ar^{40}). The sensitivity of the mass spectrometer is of the order of 5×10^{-5} amp./torr of ion current collected at the electron multiplier detector. This sensitivity is equivalent to detection of an ion peak, at 1 count/sec. of 10^{-15} torr. at 10 counts/sec. the signal to noise ratio is 2 or 3. Therefore, the practical sensitivity of the instrument is 10^{-14} torr.

The dispersion of the ion beams at the collector part of the instrument is sufficient to allow the simultaneous detection of three ion beams of mass ratio 1:12:40. This arrangement permits a scan of the mass spectrum from 1 to 160 amu (less the 5 to 11 amu range) by varying the ion sweep voltage by only a factor of 4 (nominally 300 to 1200 volts) thereby simplifying the electronics power supply and reducing the time required to scan the mass spectrum. At a 1 second per voltage step scan rate of the ion sweep voltage, the mass spectrum is scanned in 2000 seconds. An optional mode of operation allows the complete spectrum to be scanned in 200 seconds at 0.1 sec./step with a corresponding reduction in sensitivity.

The weight of the mass spectrometer package including structural and thermal configuration is 24 pounds. The power required to operate the instrument is 14 watts including the thermal control circuit, with an additional

6 watts required for a heater that operates below 0°C. Size of the complete package is 11½" x 7½" x 12".

The principal developer of the ALSEP Mass Spectrometer experiment (J. H. Hoffman) received his PhD in physics at the University of Minnesota under Prof. A. O. Nier. His dissertation involved the construction and use of a double-focussing magnetic Mass Spectrometer to study the distribution of cosmogenic helium in iron meteorites. He has had 12 years experience in the design, construction and operation of magnetic mass spectrometers, as well as data analysis for rocket and satellite experiments.

Complementing capabilities in mass spectrometry, the current research of the University of Texas at Dallas faculty includes an active program of study of planetary atmospheres and exospheres. The lunar atmosphere is of great interest to this group both as a planetary atmosphere and as the only accessible example of a classical exosphere.

Two of the other investigators, F. S. Johnson and D. Evans, are engaged in the Lunar Atmosphere Detector Experiment of the present ALSEP program. In addition, R. R. Hodges and F. S. Johnson have published the only (apparently) serious theoretical analysis of global transport of gases in the lunar atmosphere (in Journal of Geophysical Research, 73, 7307, 1968). Ongoing theoretical studies of planetary atmosphere, as well as participation in the ALSEP Lunar Atmosphere Detector Experiment and the Mass Spectrometer (SMOG) of the Lunar Orbit Science Program, ensure the degree of competence and continuity essential to realizing the scientific potential of placing the Mass Spectrometer Experiment on the lunar surface.

II. STATUS REPORT

A. CHRONOLOGY OF DEVELOPMENT OF LUNAR MASS SPECTROMETER

The developmental contract NAS9-7591 received from MSC on November 15, 1967 related to the design, development, and testing of a mass spectrometer capable of measuring the composition of the lunar atmosphere. Work was begun immediately on the design of the magnet and analyzer geometry as well as the electronic circuitry. The initial contract called for the instrument to scan the mass range from 12 to 160 amu. Eleven different electronic subassemblies were developed and tested, the details of which are described in Section III.

An electron bombardment ion source was developed with its associated emission control circuitry. In March 1968, all of the electronic circuits were designed, bread-boarded and testing was underway. Attention was then directed to the packaging of the circuits for the prototype model. Thermal and structural analyses were begun at MSC. Mechanical assembly of a bread-board analyzer and ion source was completed in May 1968, and testing was begun in the Ultra-High Vacuum Chamber at UTD. An electrostatic focusing ion source constructed for the project exhibited some space charge limiting of the electron beam. The problem was later rectified by the addition of an axial magnetic field to focus the electron beam on the trap (anode).

The Ground Support Equipment (GSE) was designed and constructed at MSC in conjunction with engineers from UTD. (The system is described in Section III.) The GSE and data detection and compression circuits of the Mass Spectrometer underwent a life test beginning in June, 1968, and continuing until November, 1968, without exhibiting a failure. The bread-board designs and tests of the Mass Spectrometer experiment were essentially

completed by October, 1968. At that time an extension of the contract to July, 1969, was approved which added the following requirements:

- 1) Design, develop, and fabricate magnetic sector tubes and associated electronics to determine mass ranges from 1 amu to 160 amu. The previous requirement was from 12 to 160 amu.
- 2) Design and develop necessary internal electronic circuits on suitable thermal boards to provide an internal operating temperature between -20°C to $+80^{\circ}\text{C}$ for proper operation on the lunar surface.
- 3) Design and develop the necessary additional ionization potential gun and associated electronic sweep circuits.
- 4) Design and develop method to provide internal calibration of the spectrometer when in a sealed configuration.

A meeting was held on October 18, 1968, at MSC between representatives of UTD and MSC for the purpose of determining the scope of the project, its definite goals, and the division of effort between the two organizations. Basically, the project now included constructing two models of the mass spectrometer experiment. The first was a Test Unit which was used for thermal and structural tests to be conducted mainly at MSC. MSC had the primary responsibility for building and testing this unit. The second model was a Prototype Unit. This unit was similar to a flight model suitable for the ALSEP Program. The responsibility for developing the analyzer tube, magnet, ion source and electronics lay with UTD. MSC developed the housing and thermal control hardware.

In December, 1968, the structural and thermal designs of the prototype were completed and a structural model constructed at MSC. Testing of this model to ALSEP qualification level vibration specifications was successfully completed on May 22, 1969. The same model was fitted with printed circuit boards having heat loads equal to the design heat dissipation of the prototype PC boards. A thermal vacuum test of lunar day and night conditions conducted in June, 1969, showed no heat dissipation problems. In general, the equipment operated at cool temperatures. See Section V for results.

The Prototype instrument was constructed simultaneously with the Structural and Thermal models. The instrument was completed in August, 1969, and tested at UTD. (See Section IV for test results.) However, a major catastrophe occurred in that a high-voltage arc destroyed a large number of integrated circuits in the digital sweep control circuit and the output detector circuitry. The problem was finally traced to a large capacitor which had no discharge path and had accidentally, through handling, discharged through the components that were destroyed. The problem was rectified, new components obtained and the Prototype environmental tests were conducted at MSC in January, 1970. The results may be found in Section V. The contract was extended to March 31, 1970, to cover these tests.

B. CURRENT STATUS OF HARDWARE

A prototype model of the Mass Spectrometer suitable for a Lunar ALSEP mission has been designed, constructed, and tested. The instrument has undergone ALSEP qualification level environmental tests at MSC, the results of which are discussed in Section V. These included both a vibration

and thermal vacuum test. The instrument passed both with no problems having been uncovered. The prototype Mass Spectrometer is shown in Figures 1-1 and 1-2. Thermal control is accomplished by an active heater control circuit in the electronics housing (the top half of the package in the picture). Heaters are operated below 0°C and turned off above 6°C . The electronics package is surrounded on five sides by a thermal blanket, and covered with surface mirrors on the top side. The mirrors are attached to a radiator plate to which the electronics printed circuit boards are tightly coupled thermally. Heat loss is by radiation from the mirrored surface.

On January 29, 1970, a contract was received at UTD to build a Mass Spectrometer for the Lunar Orbital Science Mission. This instrument is similar to the ALSEP prototype except for the mass range scanned (12-66 amu for the orbital instrument). The complete electronics circuitry has been redesigned for the orbital instrument using the ALSEP designs as a basis. Significant improvements have been made in these "second generation" circuits. The similarity between the orbital Mass Spectrometer and the ALSEP instrument is so great that approximately 70 to 80 percent of the circuits would be identical and be used unchanged (same artworks and PC cards) for a future ALSEP mission. The differences lie mainly in the command interface and the high voltage sweep stepping control circuits (a wider mass range is scanned by the ALSEP instrument). The magnetic analyzer for future instruments is similar to that developed for the ALSEP prototype and very little design work would be required in this area. The structural and thermal designs done previously would be applicable.

The Ground Support Equipment (GSE) to support testing of the Mass Spectrometer has been developed and is operational. Its functions are described in Section III.

III. TECHNICAL SPECIFICATIONS

A. MASS SPECTROMETER

The primary objective of the ALSEP Mass Spectrometer is to measure the composition of the lunar atmosphere. This was accomplished utilizing a magnetic sector-field mass spectrometer as part of an array of experiments to be placed on the lunar surface by an Astronaut. The instrument scans the mass range from 1 to 150 amu in three sections, and has a sensitivity of 10^{-14} torr.

1. System Performance Characteristics

For the following discussion, refer to the block diagram of the Spectrometer (Figure 3-1).

The mass spectrum is scanned by varying the ion-accelerating voltage in a step-wise manner and counting the number of ions collected by each of three electron multiplier detector systems during each voltage step. The mass range scanned is divided into 3 ranges, 1-4, 12-48, and 40-160 amu, each range being detected by one of the electron multipliers. This is accomplished in the following manner (refer to Figure 3-2):

Atmospheric gas molecules collected by the inlet aperture of the Mass Spectrometer are ionized by electron impact in the ion source and collimated into a beam which traverses a magnetic field that acts as a momentum analyzer. Ions following three preselected trajectories are focused on three separate collector slits and allowed to impinge on the cathodes of separate electron multipliers. The resultant electronic gain of the multiplier yields a charge

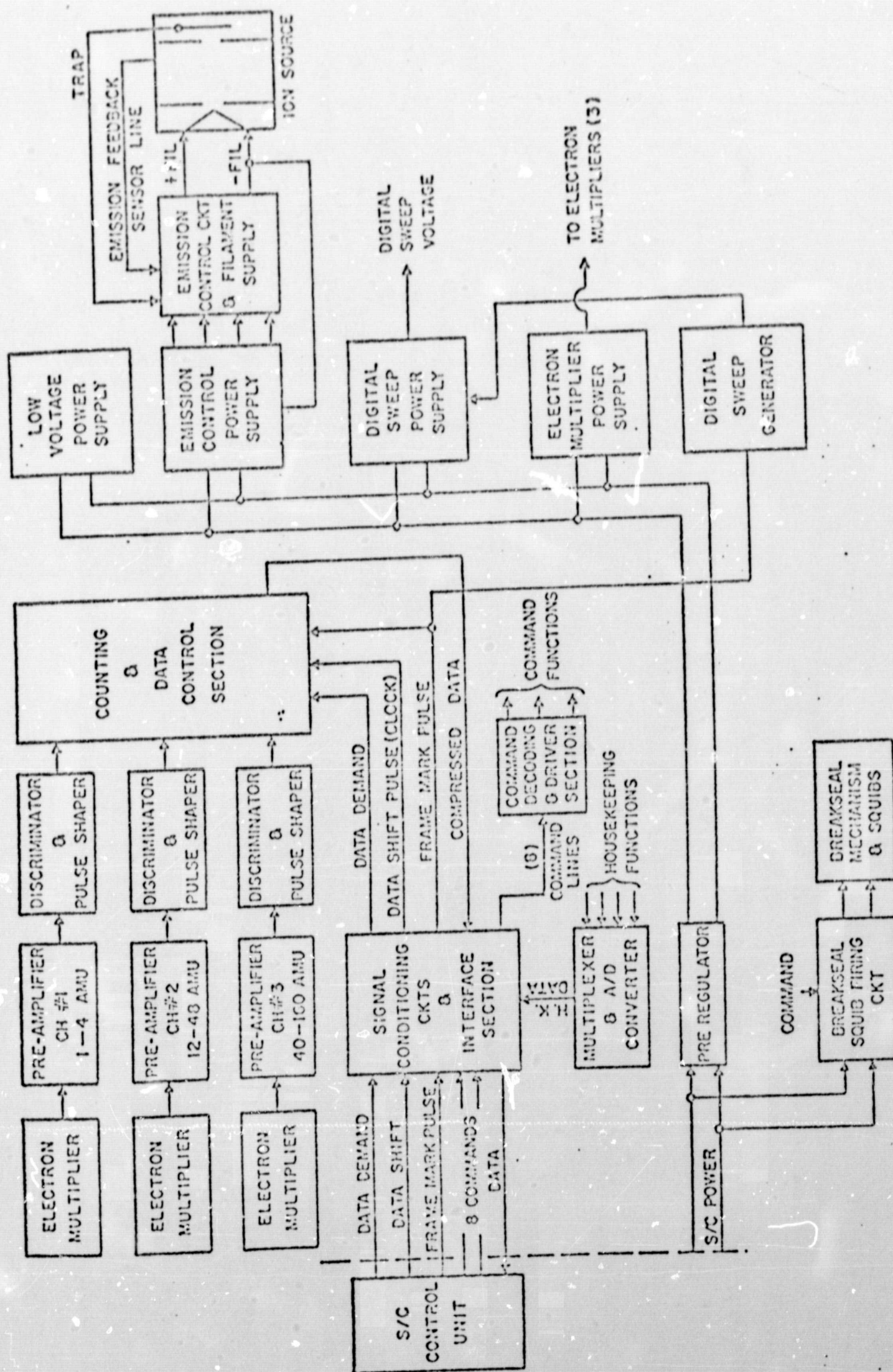


Figure 3-1. Mass Spectrometer Block Diagram

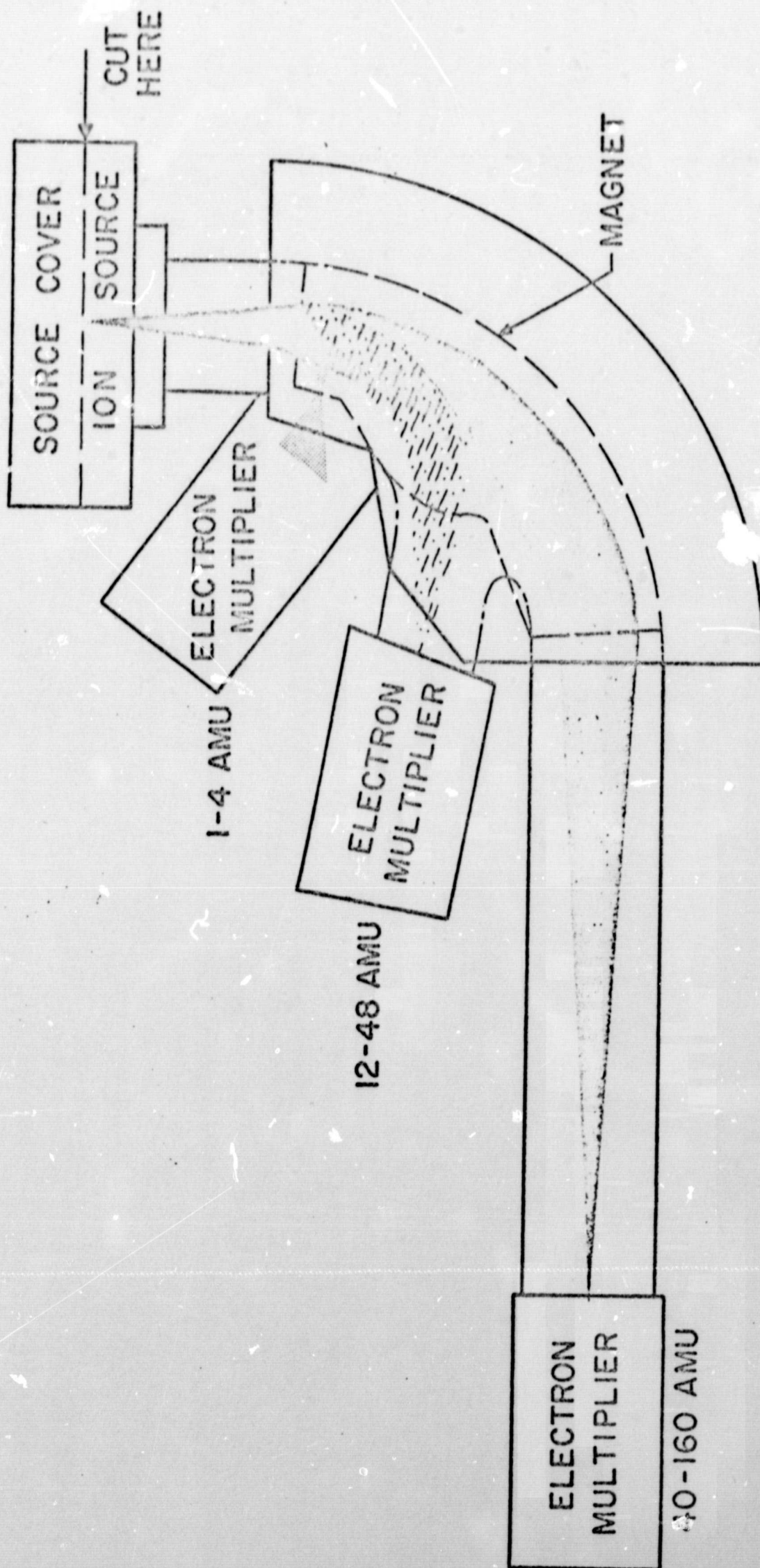


Figure 3-2. Mass Spectrometer Component Layout Diagram

pulse at its anode which is counted by pulse amplifier and counter circuitry. The ion-accelerating voltage is varied in a step-wise manner from approximately 280 volts to 1220 volts in 2000 steps. Dwell time on each step (the counting period) is not critical, but has been selected to be one second. Counts are accumulated for this period and stored in a 21-bit accumulator, (one for each channel). An enable pulse from the Data System triggers the counting period, and steps the ion accelerating voltage. Immediately following the enable pulse, the data are compressed and stored in 10-bit buffer registers to be sampled by the telemeter system within the next counting period following the data accumulation. Meanwhile count accumulation for the next voltage step occurs. Two enable pulses are received each counting period. The telemetry frame pulse initiates the start of a counting period. The voltage step number initiated by a sweep start flag determines the mass number of the ion being detected.

The ion accelerating voltage sweep is generated by varying the voltage in a series of 2000 steps from 280 volts to 1220 volts according to the following plan: 900 steps at 0.225 volts per step, 520 steps at 0.45 volts per step, 560 steps at 0.90 volts per step, 10 steps at zero volts for background counting, and 10 steps at zero volts for a calibration frequency. A flag indicates data or background and serves as a marker for the start of each sweep. The maximum range of the 1220 volt end of the sweep is ± 30 volts; maximum range of the 280

volt end of the sweep is ± 10 volts, depending on the magnetic field value. The minimum number of steps between adjacent mass peaks below mass 135 is 12 and the mass resolution is such that at mass 120 amu there is less than 1 percent contribution from adjacent peaks. At a dwell time of one second per step the sensitivity of the instrument is on the order of 10^{-14} torr. The response time of the high voltage step change is less than 10 milliseconds.

Internal calibration occurs after each sweep of the mass spectrum during the 20 zero-volt background and calibration steps by applying an internal clock output (nominally 32 KHz) to the counter inputs for the last 10 steps of this period.

a. Telemeter Format

The Data System format contains 1060 10-bit words repeated each second. Ten sets of three 10-bit words each per 1 second period contain the mass spectrometer data; a single 10-bit word bit is the sweep step counter. In addition, a single zero to five analog housekeeping channel is provided. Fifteen (15) instrument parameters are monitored, commutated internally to the instrument and outputted sequentially on this channel. The housekeeping monitors are shown in the following list.

1. -12 volts
2. +5 volts
3. +12 volts
4. Spare
5. A/D Calibration

6. Filament current
7. Instrument current
8. H.V. multiplier monitor
9. H.V. sweep monitor
10. Temperature no. 1 (electronics)
11. Temperature no. 2 (mass spectrometer)
12. Spare
13. Flags
14. Spare
15. -16V reference

Summary of telemeter requirements:

5 10-bit words/1 second

b. Commands

Eight up-leg command words, 5 of which are encoded by pairs give 13 discrete command functions. These are tabulated below.

<u>Command No.</u>	<u>Command Generated</u>	<u>Command No.</u>	<u>Command Generated</u>
1, 2 & 6	Survival	4, 5 & 6	Multiplier LO
1, 3 & 6	Operate	6	Command Clear
1, 4 & 6	Discriminator HI	7 & 6	Dust Cover
1, 5 & 6	Discriminator LO	8 & 6	Breakseal
2, 3 & 6	Filament #1		
2, 4 & 6	Filament #2		
2, 5 & 6	Multiplier HI		
3, 4 & 6	Emission OFF		
3, 5 & 6	Emission ON		

2. Subsystem Performance Characteristics

For purposes of discussion relating to functional subsystem levels, the Mass Spectrometer is divided into the Data Subsystem, Ion Source and Control Subsystem, Sweep High Voltage Subsystem, Power Converter Subsystem, and the Thermal Control, Housekeeping Monitor and Signal Conditioning Subsystem. Refer to Figures 3-3 through 3-7 for subsystem block diagrams.

a. Data Subsystem

The Data Subsystem (Figure 3-3) consists of the high voltage power supply, electron multiplier, preamplifier, discriminator and pulse shaper, prescaler, and counter and data compressor.

The electron multiplier high voltage power supply requires voltage inputs of -12 volts, +12 volts, and +20 volts in addition to the multiplier gain control voltage. It supplies a nominal output voltage of 3500 volts which is adjustable by command.

The electron multiplier (ion collector) has a gain of 10^6 and functions as collector for the ions which pass through the magnetic analyzer. Three electron multipliers are required in the Spectrometer, one for each mass range channel. (Refer to Section III A-1). Each ion striking the multiplier cathode produces an output pulse which is counted.

Basically an AC amplifier with approximately 60 db gain, the preamplifier amplifies the pulse output of the electron multiplier to a usable level for the discriminator and pulse shaper.

The input reference level of the discriminator is controlled by

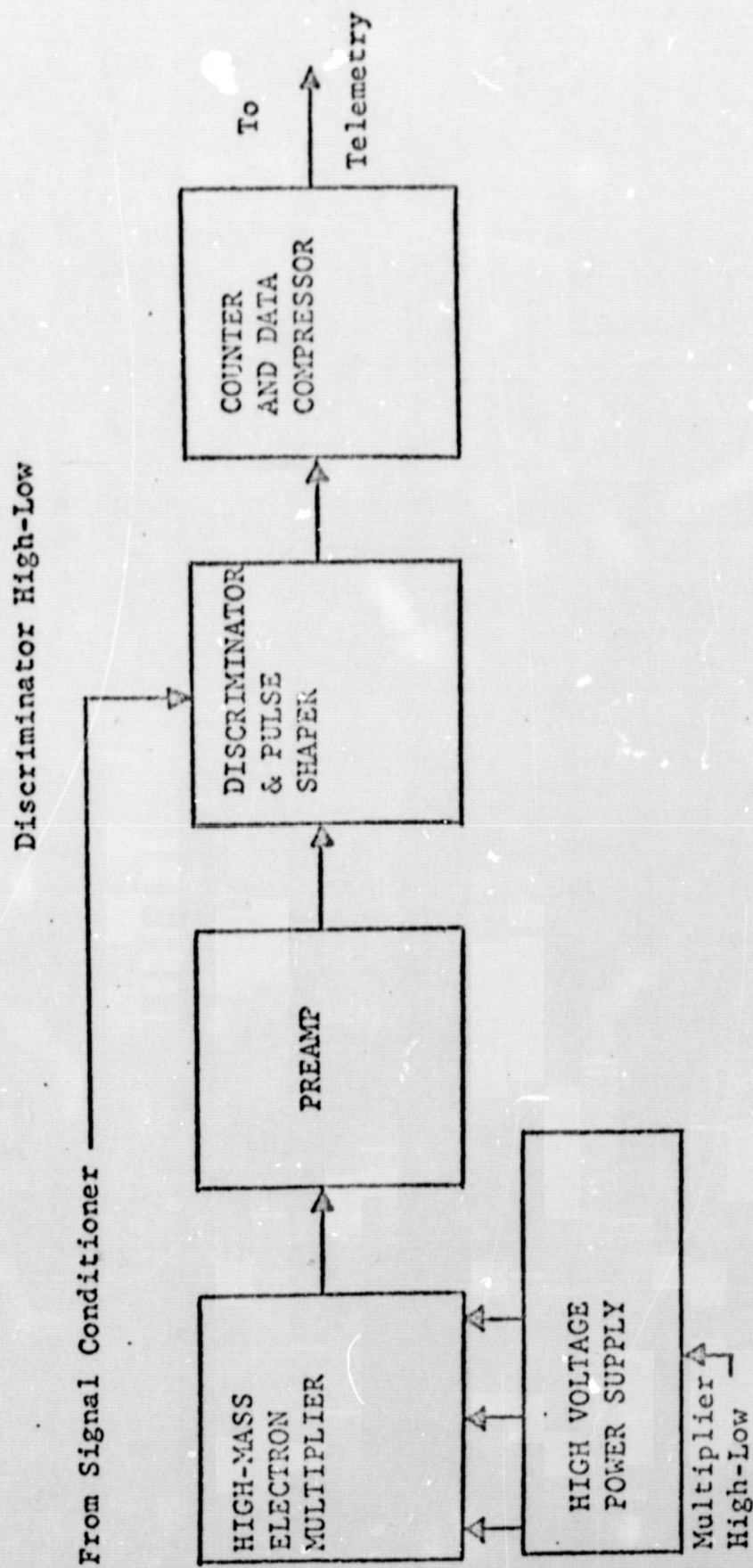


Figure 3-3. Data Subsystem Block Diagram
(3 Channels)

command. This command can set the discriminator's sensitivity level at one of two values such that a noise pulse will not trigger the discriminator. A pulse amplitude exceeding the preset cutoff level of the discriminator will cause the discriminator to conduct and will produce a pulse output.

The counter and data compressor converts a 21-bit number into 10 bits for readout. Steps in which the data are compressed are as follows (refer to the following figure for a typical data compressor output):

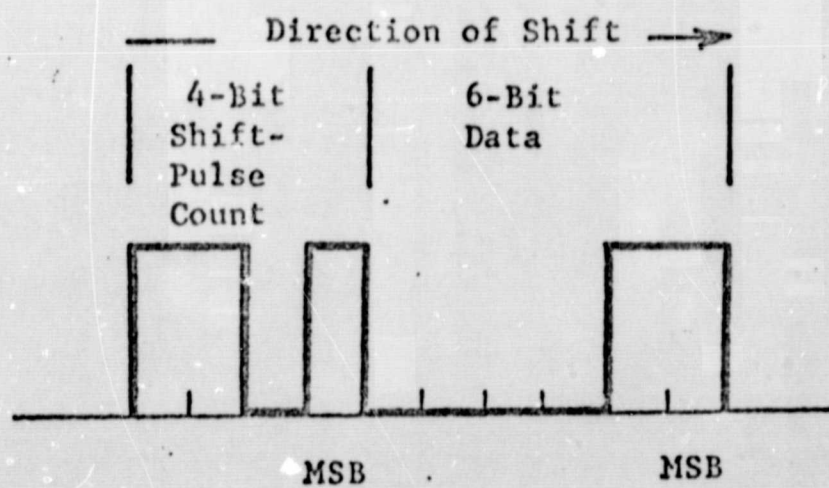
1. The data number is transferred from a 21-bit counter to a 21-bit shift register.
2. Shifting of the data number begins. A shift counter is used to count each shift pulse.
3. The shifting process stops when the most significant one bit (MSB) of the data number is detected in the last stage of the shift register.
4. The six bits following this MSB are saved for readout. This number is called "D".
5. The number of shifts is transferred to the four stages in the shift register immediately behind the number "D". This shift count is called "S".
6. A maximum of $21 - 7 = 14$ shifts is allowed. These 14 shifts will position the six lowest significant bits so they will be equal to "D".

7. Shift count 14 stops the shifting process whether MSB is equal to 1 or 0. The counter will increment to 15 if MSB = 0. If MSB = 1, the shift counter will remain at 14. The 6-bit number "D" will be read out first starting with the most significant bit. "S" follows with its most significant bit first. The equation for reconstructing the value of the 10-bit register bit is:

$$(D264) 2^{14-S}, \text{ if } S=14$$

$$D, \text{ if } S=15$$

When the shift count is S-14, the MSB is always equal to 1. Therefore, the value 64 must be added to obtain the correct data value. When S=15 the MSB=0, and no correction to "D" is required.



Typical Data Compressor Output

b. Ion Source and Control Subsystem

The Ion Source and Control Subsystem (Figure 3-4) consists of the emission control circuit, and the ion source. Two filaments are available for redundancy. The following paragraphs provide a discussion of subsystem performance characteristics.

The emission control circuit is used to control and switch the filament voltages in case of failure of the operating filament. The operating filament, requiring approximately 1.6 amps, is at a potential of -80 volts with respect to the ionization chamber, and the standby filament, which serves as an electron trap, is maintained at a +45 volts referenced to sweep voltage. Additional functions include application and control of voltages on the focus grid, ion chamber, and J plates number 1 and 2. The potential on the focus grid is -3 volts referenced to sweep voltage, and the ion chamber has the ion-accelerating sweep voltage applied to it. This sweep voltage, which is a series of voltage steps, provides the Mass Spectrometer's ability to scan the ion spectrum.

The ion source performs the function of ionization by electron bombardment of the atmospheric gas molecules, accelerating these ions and forming a collimated beam directed into the magnetic analyzer.

c. Sweep High Voltage Subsystem

The Sweep High Voltage Subsystem (Figure 3-5) consists of the sweep high voltage power supply and the digital sweep control circuit. A discussion of their performance characteristics is presented in the following paragraphs.

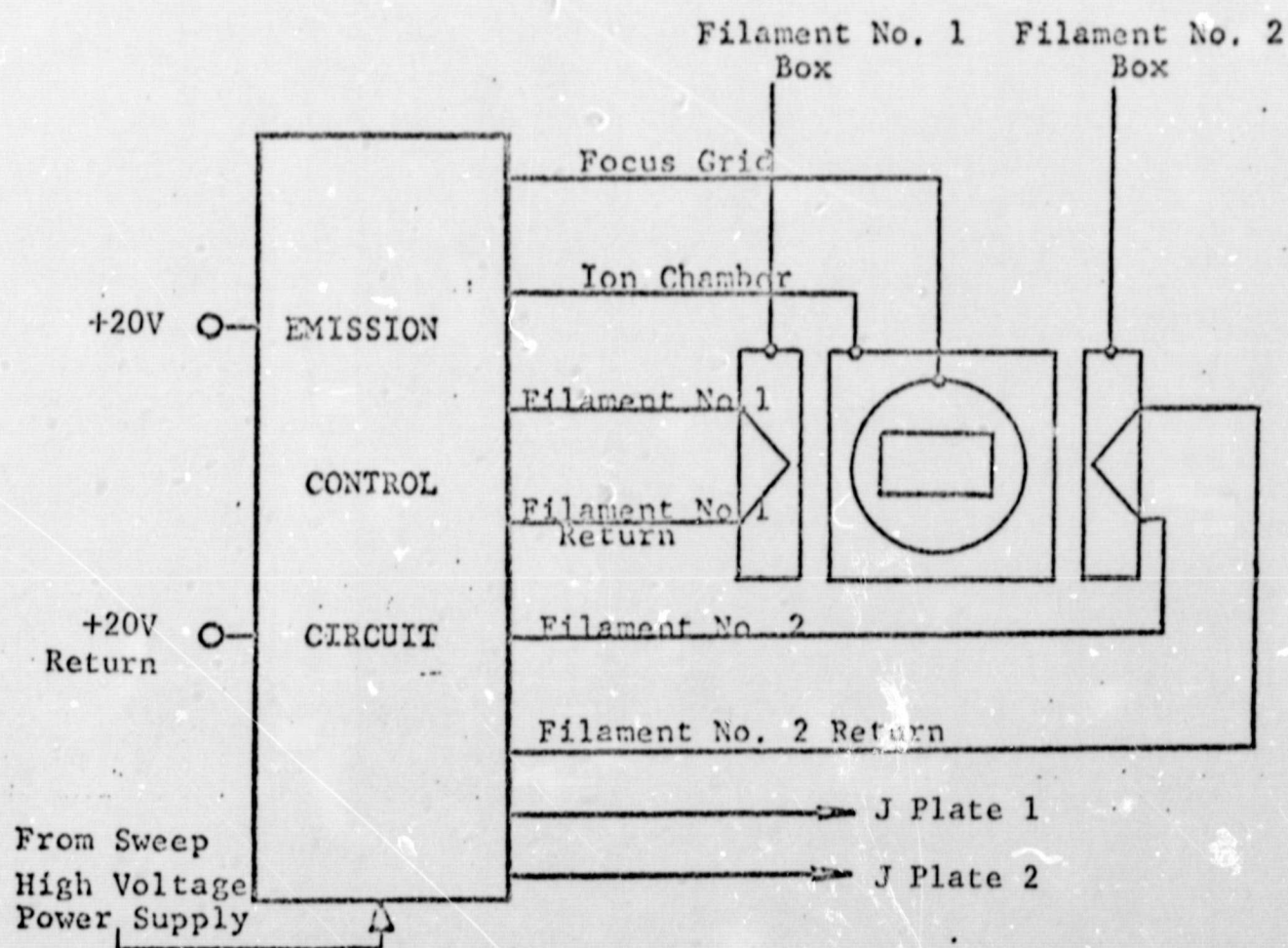


Figure 3-4. Ion Source and Control Subsystem Block Diagram

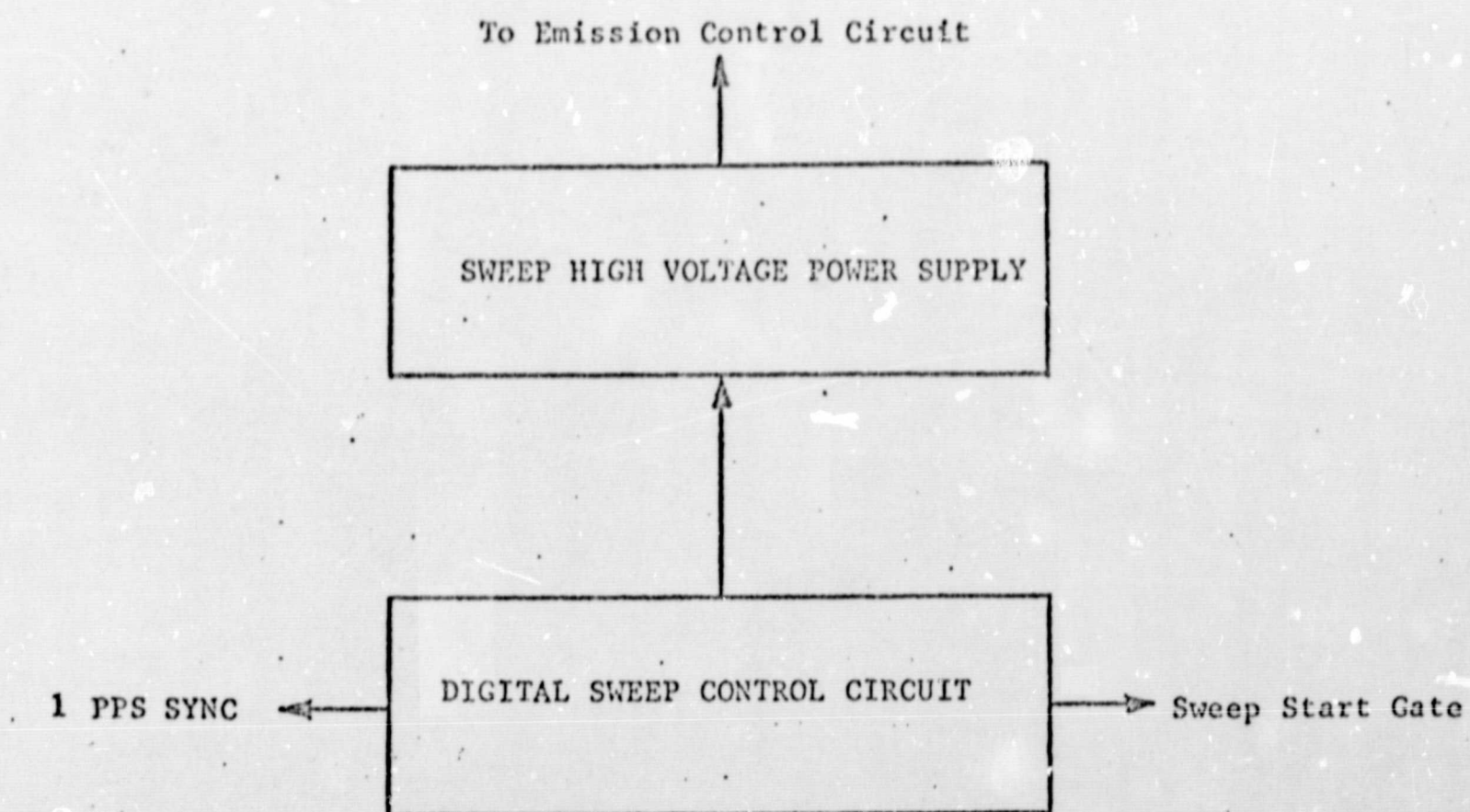
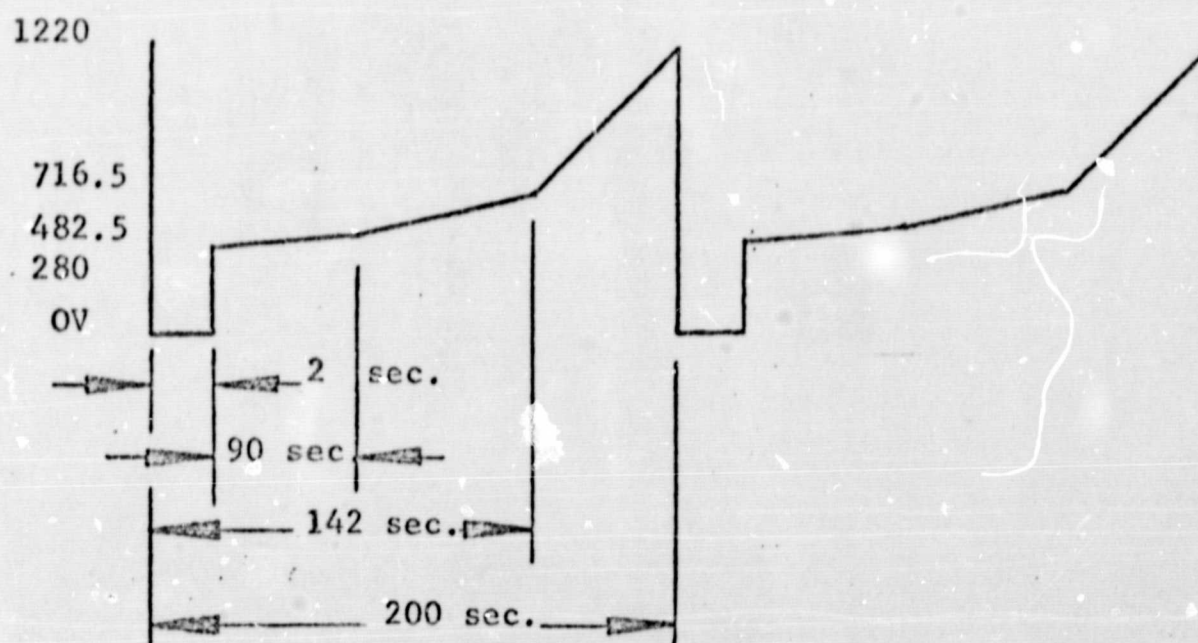


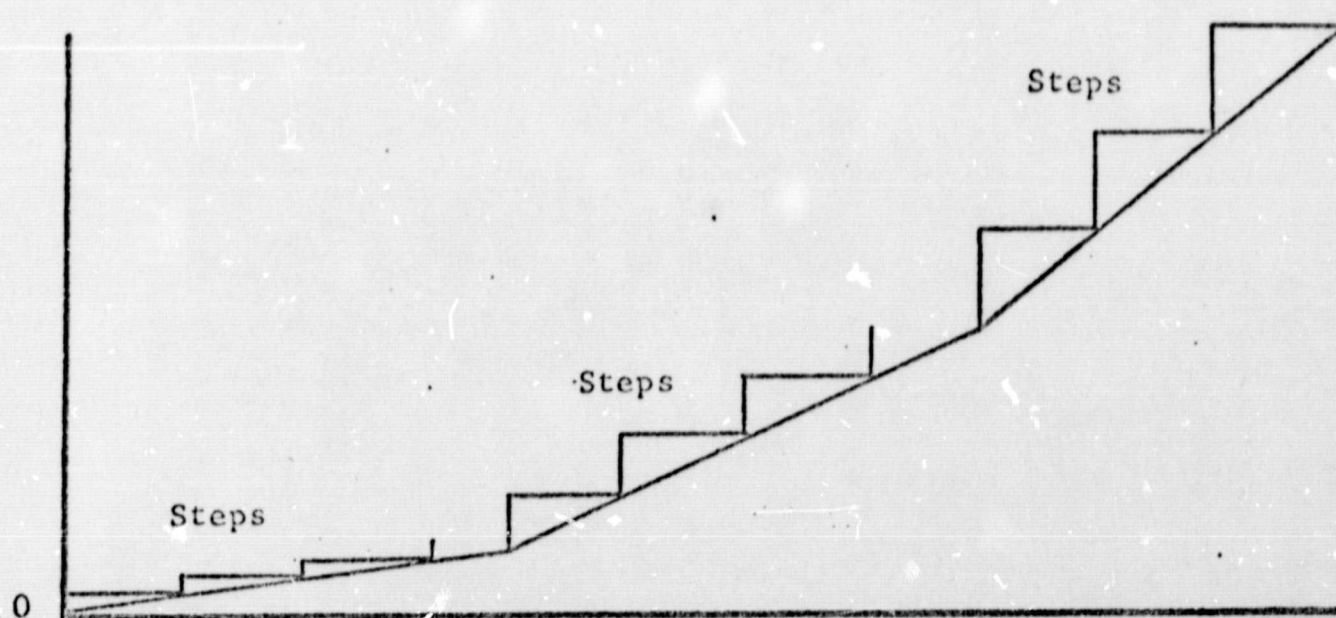
Figure 3-5. Sweep High Voltage Subsystem Block Diagram

The sweep high voltage power supply develops the high voltage level on which the ion source rides. The circuit obtains +20V from the switching pre-regulator, and the two control signals (sweep and pedestal) from the digital sweep control circuit. This combination provides an output voltage which sweeps from 0 volts to 1220 volts in the following manner:



After setting in the background count mode (0 volts) for twenty counting periods (equivalent to 20 zero volt steps) the output begins to increase in a stepwise manner from 280V by 0.225 volt steps (900) until it reaches 482.5. The step size then doubles to 0.45 volt/step for 520 additional steps to 716.5 volts. The step size again doubles to 0.90 volts/step for 560 steps to 1220 volts. The total number of steps, including the background mode is 2000, at 0.1 sec/step the sweep time is 200 seconds. The output now returns to zero volts and the sweep cycle starts over.

The digital sweep control circuit develops a sweep output and a pedestal output. Together these two outputs control the sweep high voltage power supply. These outputs are referenced to the 10 PPS or 1 PPS input (10 steps/sec. or 1 sec/step). The sweep output consists of three straight lines which approach an exponential as shown.



d. Power Converter Subsystem

The Power Converter Subsystem (Figure 3-6) consists of the switching pre-regulator and the low voltage power supply.

The switching pre-regulator obtains 28 volts from the Central Station and provides a regulated +20V to ± 0.25 V output, at more than 85 percent efficiency. This output is used for the low voltage power supply, the sweep high voltage power supply, the multiplier high voltage power supply, and the emission control circuit. In the event the output is shorted or overloaded, the circuit will operate in the current limit mode and will drain less current from the CS than in the normal mode. The input is also designed to accept rather large voltage spikes (50V) on the CS input line.

The low voltage power supply accepts the +20 volts from the switching pre-regulator and develops -25 volts, +12 volts, -12 volts, +15 volts, -16 volts reference, +5 volts and -7.5 volts. These voltages are used throughout the instrument. In the event of

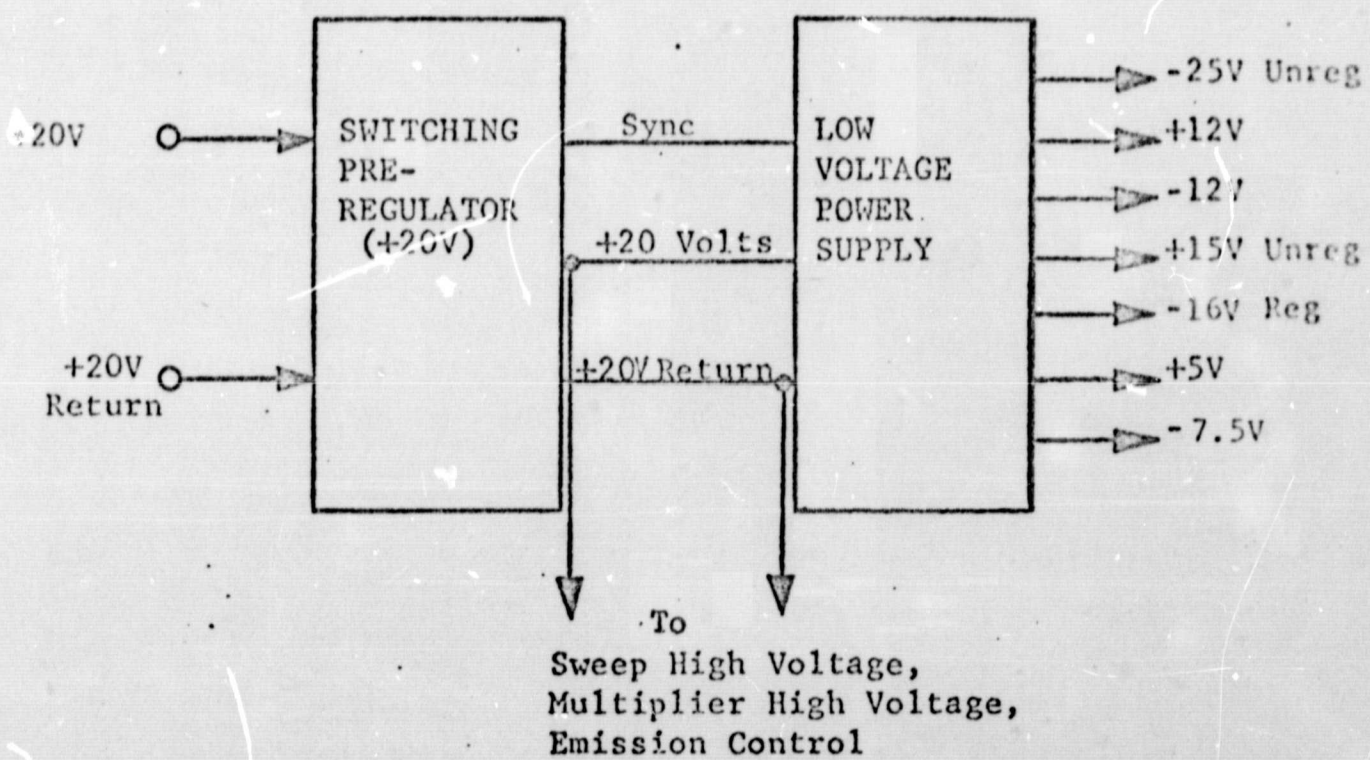


Figure 3-6. Power Converter Subsystem Block Diagram

a drive oscillator failure, the circuit will self-oscillate and continue to provide all outputs at a slightly reduced efficiency.

e. Thermal Control, Housekeeping Monitor,
and Signal Conditioning Subsystem

This Subsystem (Figure 3-7) consists of thermal control, housekeeping monitor, and signal conditioning circuits installed on printed circuit boards.

The thermal control circuitry consists of the -12 volt monitor, -16 volt reference monitor, instrument current monitor, mass spectrometer temperature monitor, electronic temperature monitor, and thermal control. It performs its function of regulating Spectrometer temperature by utilizing these reference, monitor, and control circuits to switch on and off a pair of patch heaters. Housekeeping and monitor circuits consist of the multiplexer, output buffers, and a divide-by-ten counter. The multiplexer samples 15 analog monitors at the rate of one per second and converts the information to a digital word.

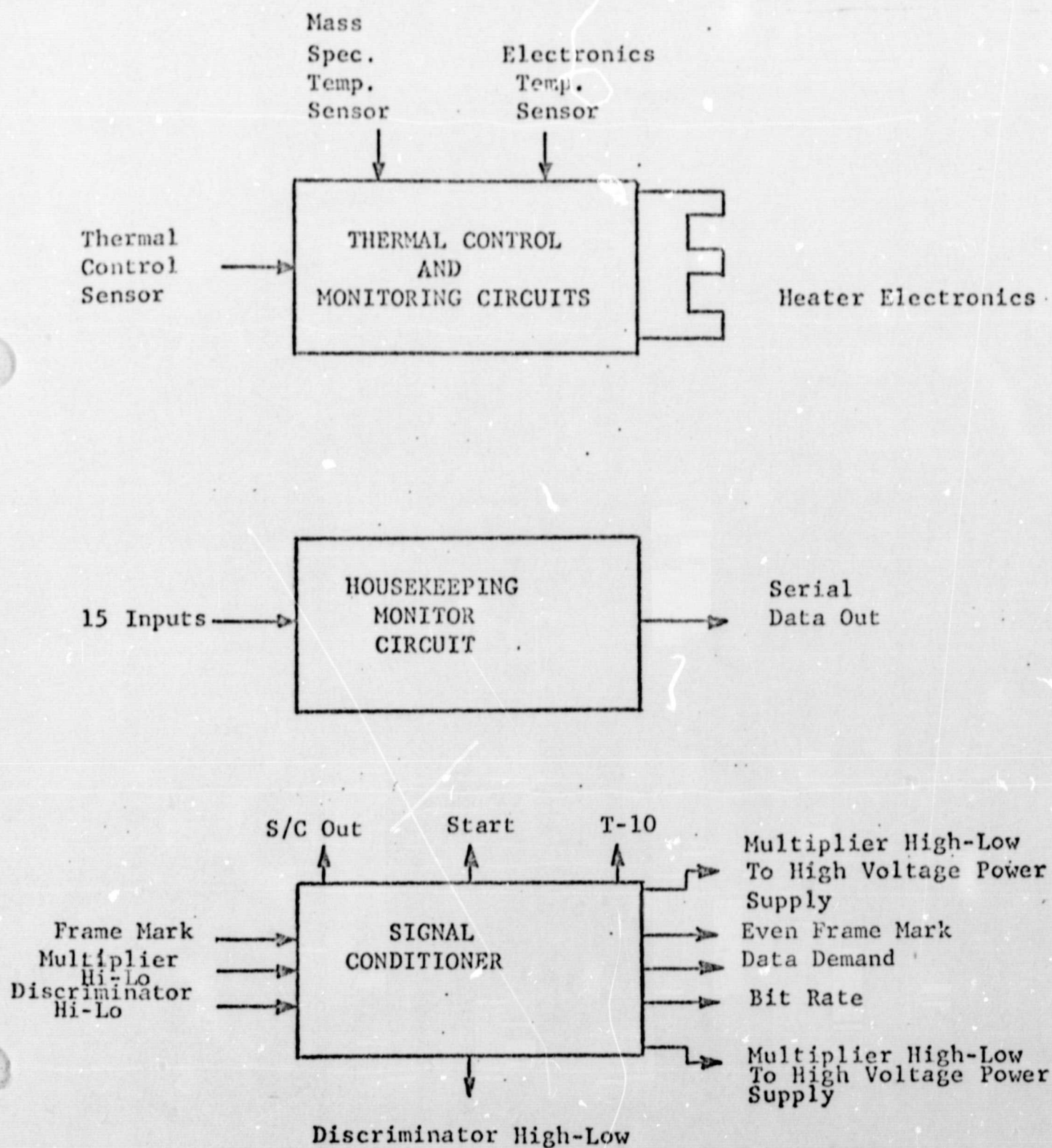


Figure 3-7. Thermal Control, Housekeeping Monitor, and Signal Conditioner Subsystem Block Diagram

The divide-by-ten counter receives the buffered 10 PPS from the Command Station and generates a 1 Hz pulse stream which is used in the multiplexer, and a sync pulse for the diagnostic GSE.

3. Component Performance Characteristics

The component level treatment of the Mass Spectrometer consists of dividing the PC boards and other components into separate and discrete functional entities. Schematic diagrams of the PC boards are provided for a better understanding of the individual component. (Refer to Figures 3-8 through 3-18). For a more detailed discussion of performance characteristics, refer to subsystem discussion in Section III A-2.

a. Multiplier High Voltage Power Supply

The power supply outputs identical voltage outputs to Channels A, B and C. Discrete circuits of the multiplier high voltage power supply (Figure 3-8) consist of the following:

<u>Circuit</u>	<u>Characteristics</u>
1. DC to DC converter	Converts input voltage for Spectrometer use
2. Control loop op-amps	Voltage control
3. Temperature sensitive resistor	Voltage control
4. Output filter	

b. Electron Multiplier

The electron multiplier (Figure 3-2) is reduced to separate components

as follows:

<u>Component</u>	<u>Characteristics</u>
1. Cathode	Ion-electron conversion
2. Dynodes	Electron multiplication
3. Anode	

c. Preamplifier

The preamplifier (Figure 3-9) is basically a straight-forward ac amplifier. There is one each preamplifier in Channels A, B and C.

d. Discriminator and Pulse Shaper

These two circuits (Figure 3-9) are divided down to their lowest functional level and their titles describe their function. There is one each discriminator and pulse shaper in Channels A, B and C.

e. Analog to Digital Converter

The analog to digital converter (Figure 3-10) converts housekeeping analog signals to an 8-bit digital word for use in telemetry readout.

f. Counter and Data Compressor

There is one each counter and data compressor in Channels A, B and C. Circuit delineation of the counter and data compressor (Figure 3-11) is as follows:

<u>Circuit</u>	<u>Characteristics</u>
1. Timing and control	Reference
2. 21-bit counter	Counts each shift pulse
3. 21-bit shift register	Data compression
4. Shift pulse counter	Stops shifting process

g. Emission Control

The emission control (Figure 3-12) selects and controls the filament which is the source of electrons in the ion source.

Discrete circuits are as follows:

<u>Circuit</u>	<u>Characteristics</u>
a. DC to DC converter	T1 designed with 1600 volts isolation
b. Emission 1 detector	Filament fails, 5 second delay, 30 msec. one-shot pulse output
c. Bistable (Flip-flop multivibrator)	Triggered by 30 msec. pulse
d. Emission current regulator	Emission current at constant level
e. Filament monitor	Sense current in filaments
f. Sweep voltage dropping network	Provides voltage for drawout and plates J1 and J2

h. Sweep High Voltage Power Supply

The following list shows the circuits contained within the sweep high voltage power supply (Figure 3-8).

<u>Circuit</u>	<u>Characteristics</u>
1. DC to DC converter	Converts input voltage for Spectrometer use
2. Control loop op-amps	Voltage control
3. Temperature sensitive resistor	Voltage control
4. Output filter	

i. Digital Sweep Control

The digital sweep control (Figure 3-13) consists of the following

circuits:

<u>Circuit</u>	<u>Characteristics</u>
a. Binary counters	These circuits are used to develop a sweep and pedestal output for control of the sweep high voltage
b. Logic circuits	
c. Digital/analog converter	

j. Switching Pre-Regulator

The switching pre-regulator (Figure 3-14) consists of the following:

<u>Circuit</u>	<u>Characteristics</u>
a. Input filter	Input designed to accept voltage spikes of 50 volts
b. Pre-regulator	0.6 amps current (normal)
c. Blocking oscillator	Provide operation in case of failure in normal mode
d. Scales (Flip-flop)	Scales 50 KHz to 25 KHz
e. Fold-back current limiter	
f. Output filter	

k. Low Voltage Power Supply

Discrete circuits contained in the low voltage power supply (Figure 3-15) are as follows:

<u>Circuit</u>	<u>Characteristics</u>
a. Input filter	Filter and isolation
b. Inverter drive	
c. DC to DC converter	Converts input voltage for use in Spectrometer
d. Low voltage regulator	Regulates output
e. Failure mode	Self-oscillation provides power at reduced efficiency

1. Thermal Control

Thermal control circuits (Figure 3-16) are contained in the following list:

<u>Circuit</u>	<u>Characteristics</u>
a. -12 volt monitor	Utilizes the reference, monitor, and control circuits to switch on and off a pair of patch heaters.
b. -16 volt monitor	
c. Instrument current monitor	
d. Mass Spectrometer temperature monitor	
e. Electronic temperature monitor	
f. Thermal control	

m. Housekeeping Monitor

Housekeeping monitor circuits (Figure 3-17) are listed as follows:

<u>Circuit</u>	<u>Characteristics</u>
a. Multiplexer	Samples 15 analog monitors
b. Output buffers	Ensure minimum deterioration of signal
c. Divide-by-ten counter	Receives buffered 10 PPS input and generates 1 Hz pulse stream for multiplexer and sync pulse for diagnostic BTB.

n. Signal Conditioning

Signal conditioning (Figure 3-18) consists of the following:

<u>Circuit</u>	<u>Characteristics</u>
a. Switching circuits	Switch gains for high and low mass

4. System Physical Characteristics

a. Configuration

Size - 11-1/2" x 7-1/2" x 12"

Weight - 24 pounds maximum

A base plate bisects the 12" dimension. The electronics are mounted on one side, the analyzer on the other. A magnetic (conetic) shield encloses the analyzer section.

b. Magnetic Analyzer

A magnetic analyzer consists of an ion source, drift tube, three collector slits, three electron multipliers and a permanent magnet. Three ion beams emerge from the magnet after traversing paths of radii 0.39, 1.37 and 2.50 inches in the magnet gap and impinge upon separate collector slits. The mass ranges scanned across each collector are from 1 to 4 amu (low mass), 12 to 48 amu (intermediate mass), and 40 to 160 amu (high mass).

c. Ion Source

1. Electron bombardment type.
2. Two filaments for redundancy.
 - a) Selection manual by command.
 - b) Filament current - 2 amps maximum - (monitored as a housekeeping function).

- c) Filament voltage - Approximately 1 volt.
- d) Emission current - Approximately μA .
- e) Electron energy - 80 eV.

- 3. Trap - +45 volts (fixed) with respect to shield (sweep voltage).
Tolerance ± 5 volts.

The following electrodes derive their potentials from a voltage divider between the sweep high voltage and ground.

- 4. J. Plates (2) - Approximately 10 percent below sweep voltage (independently adjustable).
- 5. Focus Plate - Approximately 0.5 percent below sweep voltage.

d. Magnet

- 1. Columax 5.
- 2. 1/8" thick pole faces.
- 3. Gap - $0.220" \pm 0.001"$.
- 4. Field strength - 4700 ± 150 gauss.

e. Detector

An electron multiplier and counting system follows each collector slit. Each counting system is capable of counting uniform pulses at a 8 mHz rate and storing the data in a 1-bit accumulator. The data stored in the accumulator is compressed in a pseudo-logarithmic fashion to a 10-bit word with 7-bit accuracy and stored in a buffer register. Transfer of the data to the Data System is accomplished by a serial pulse train activated by an enable pulse from the Data System.

f. Electron Multiplier

<u>Type</u>	<u>Voltage Range</u>	<u>Load</u>
Ampex P152	-3500	100 Megohms

Dark Current - Less than 1 Picoamp at a gain of 10^7 .

Gain - Minimum output pulse: 2×10^{-14} coulomb.

Voltage Stability - ± 100 volts.

The two voltages are selectable by command.

g. Counting System

1. Pulse pair resolution 0.5 μ sec.
2. Maximum counts per step -10^6 .
3. Maximum counting rate - 2mHz.
4. Background counting rate - Less than 4 counts/second at discriminator setting of 60 db below 1 volt.
5. Counting period - 1 second.

One period per second synced to TM system.

Two discriminator levels are selectable by command.

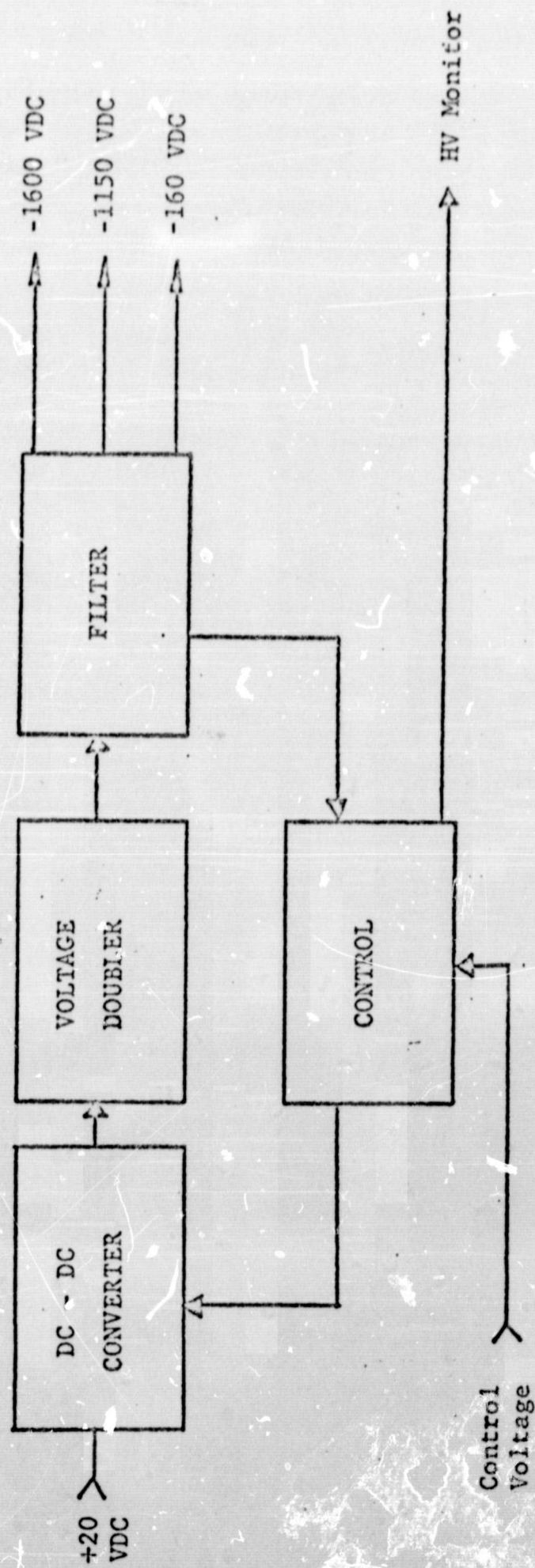


Figure 3-8. Multiplier High Voltage Power Supply Block Diagram

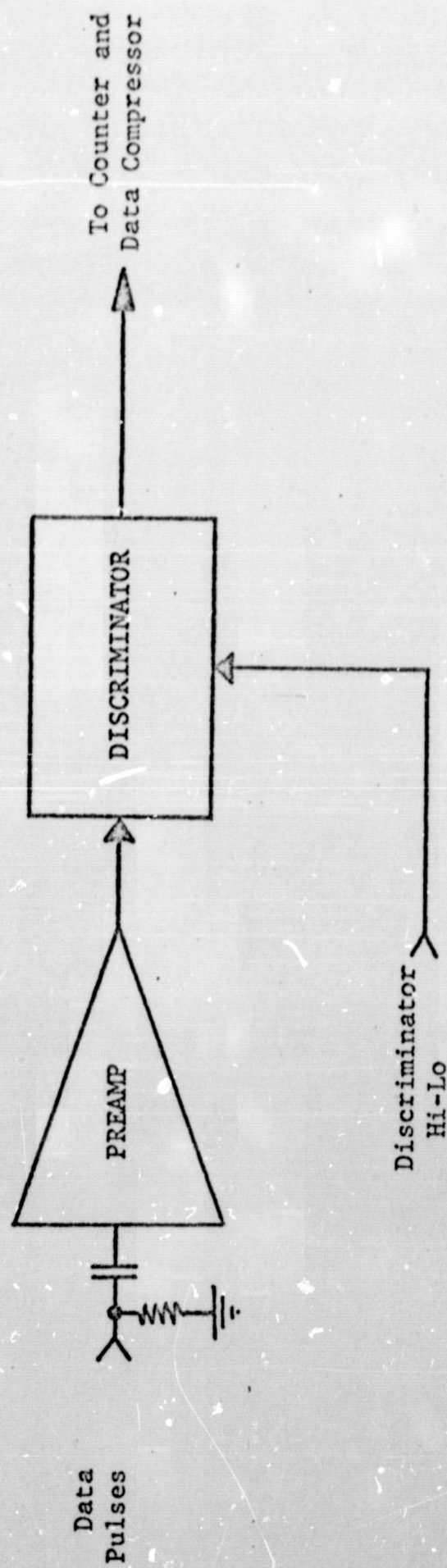


Figure 3-9. Preamplifier and Discriminator Block Diagram
(3 Channels)

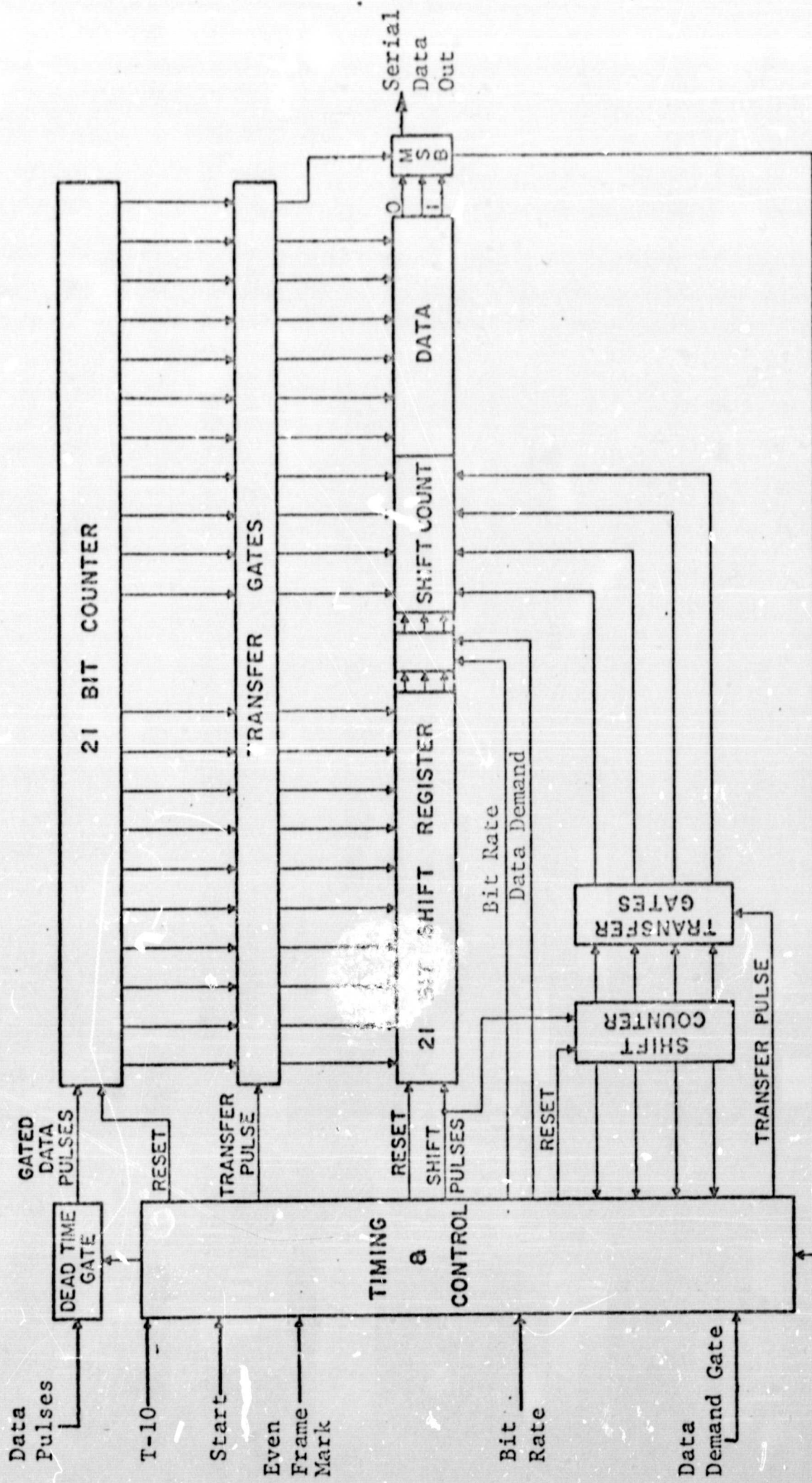


Figure 3-10. Counter and Data Compressor Block Diagram

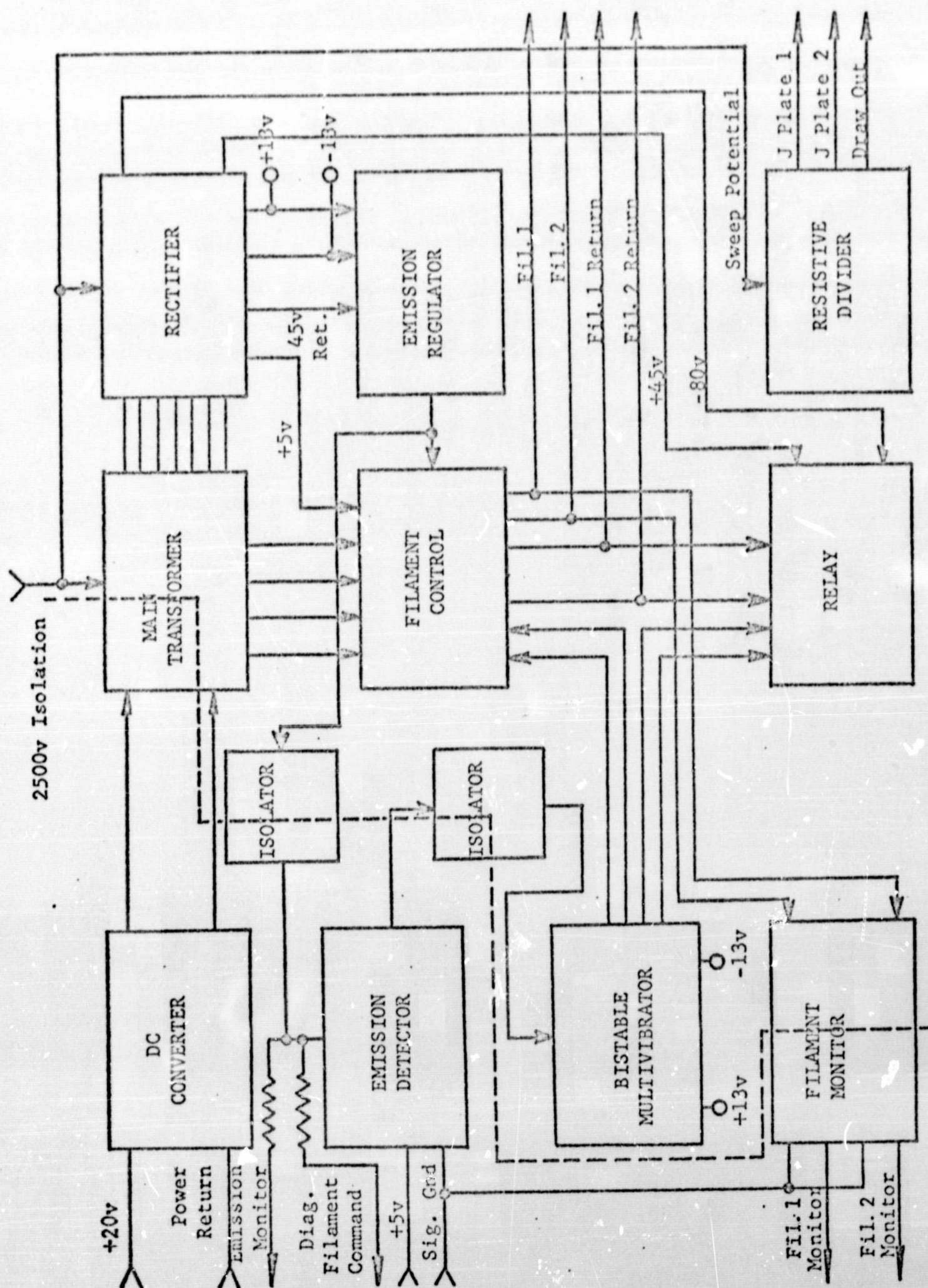


Figure 3-11. Emission Control Block Diagram

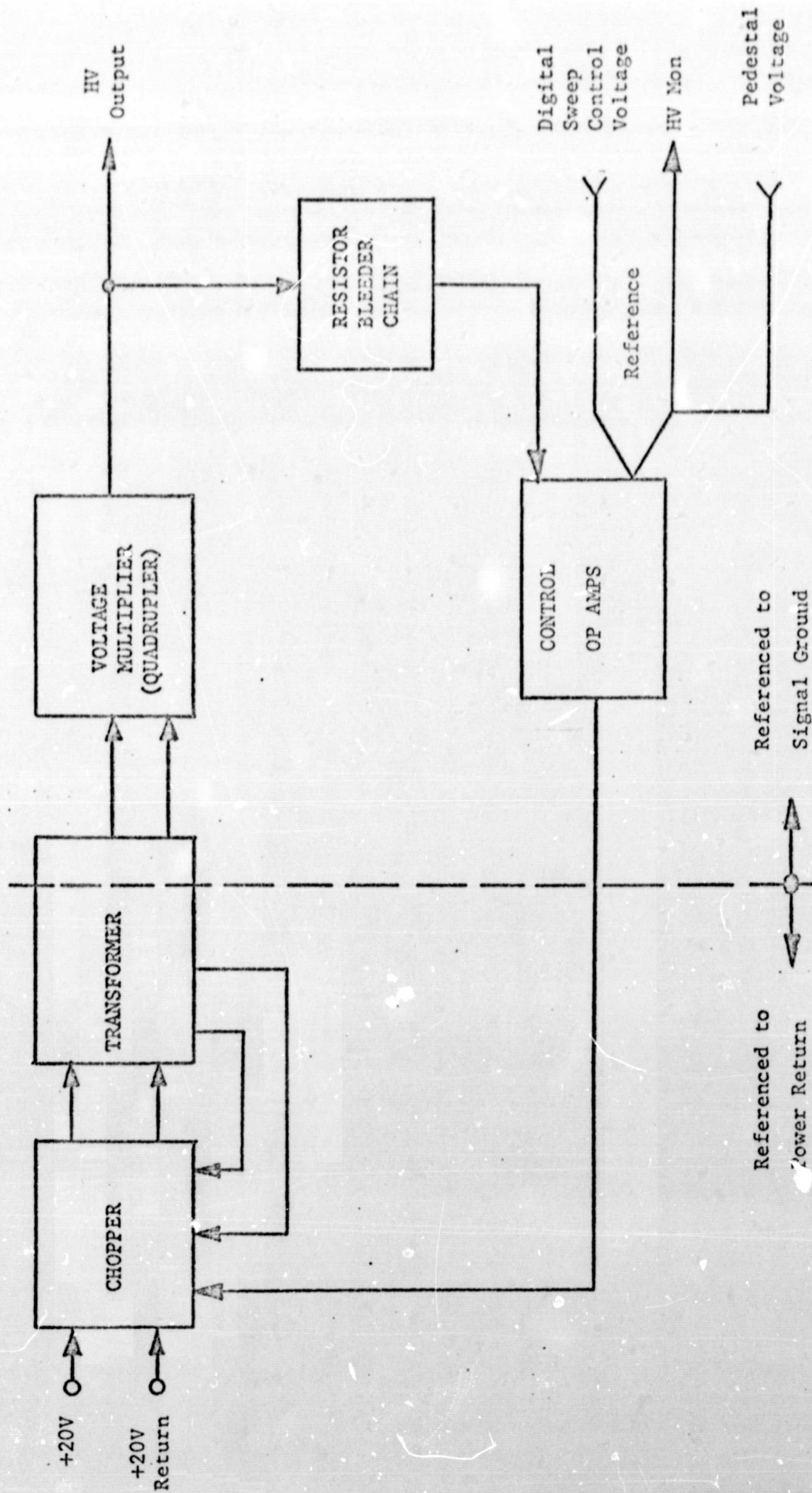


Figure 3-12. Sweep High Voltage Power Supply Block Diagram

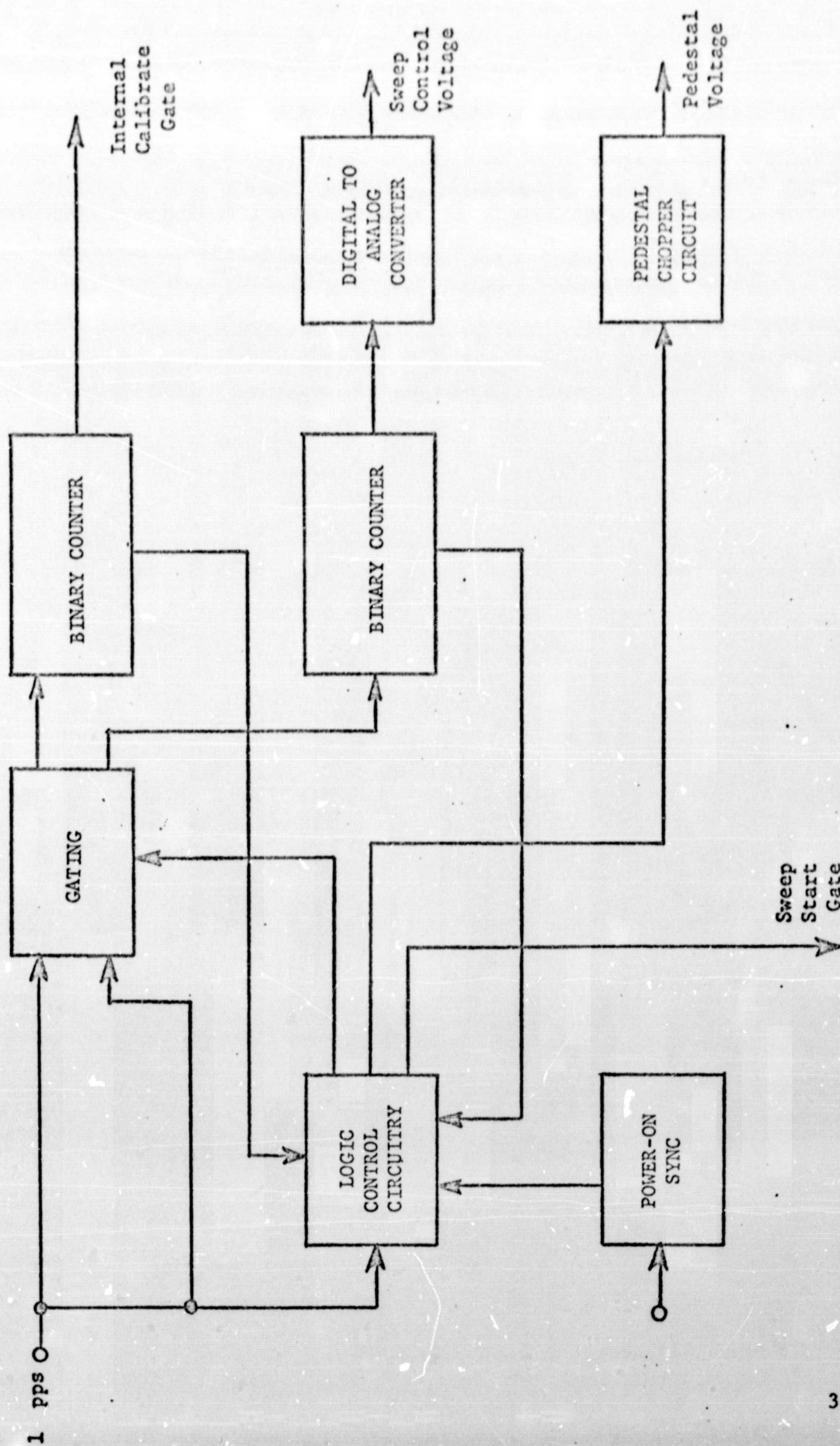


Figure 3-13. Digital Sweep Control Block Diagram

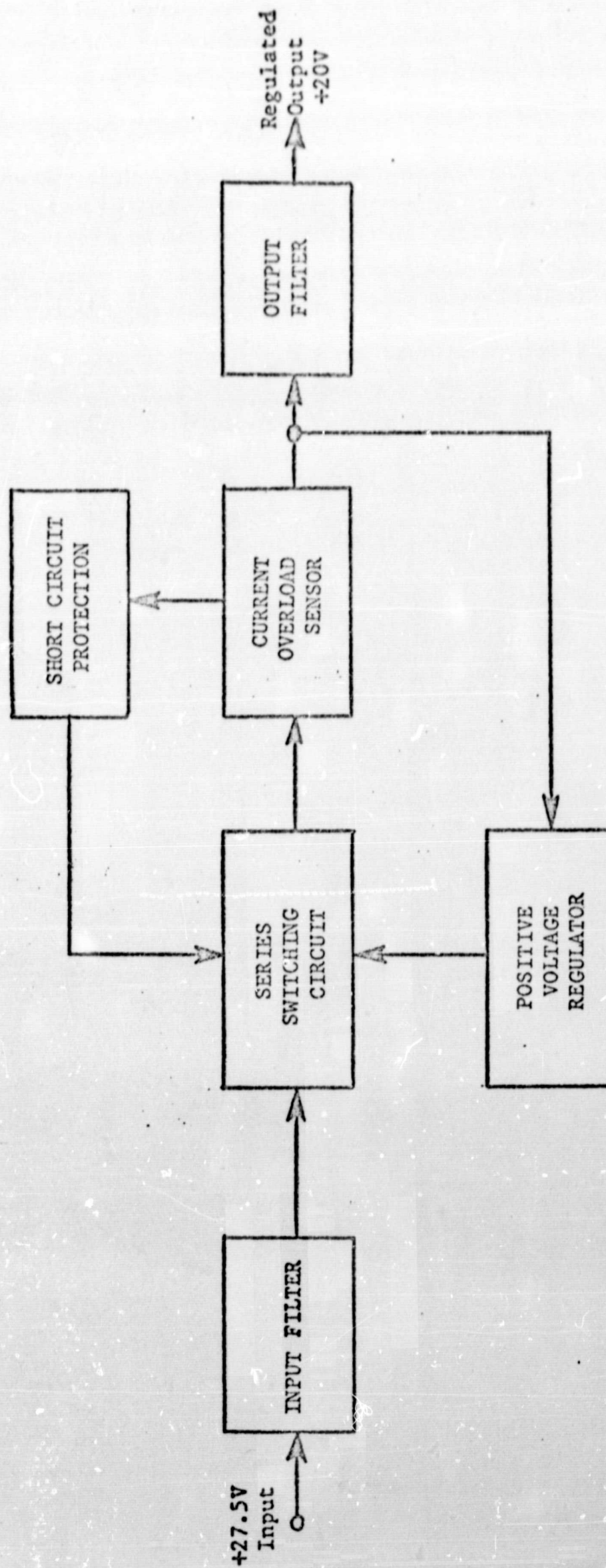


Figure 3-14. Switching Pre-Regulator Block Diagram

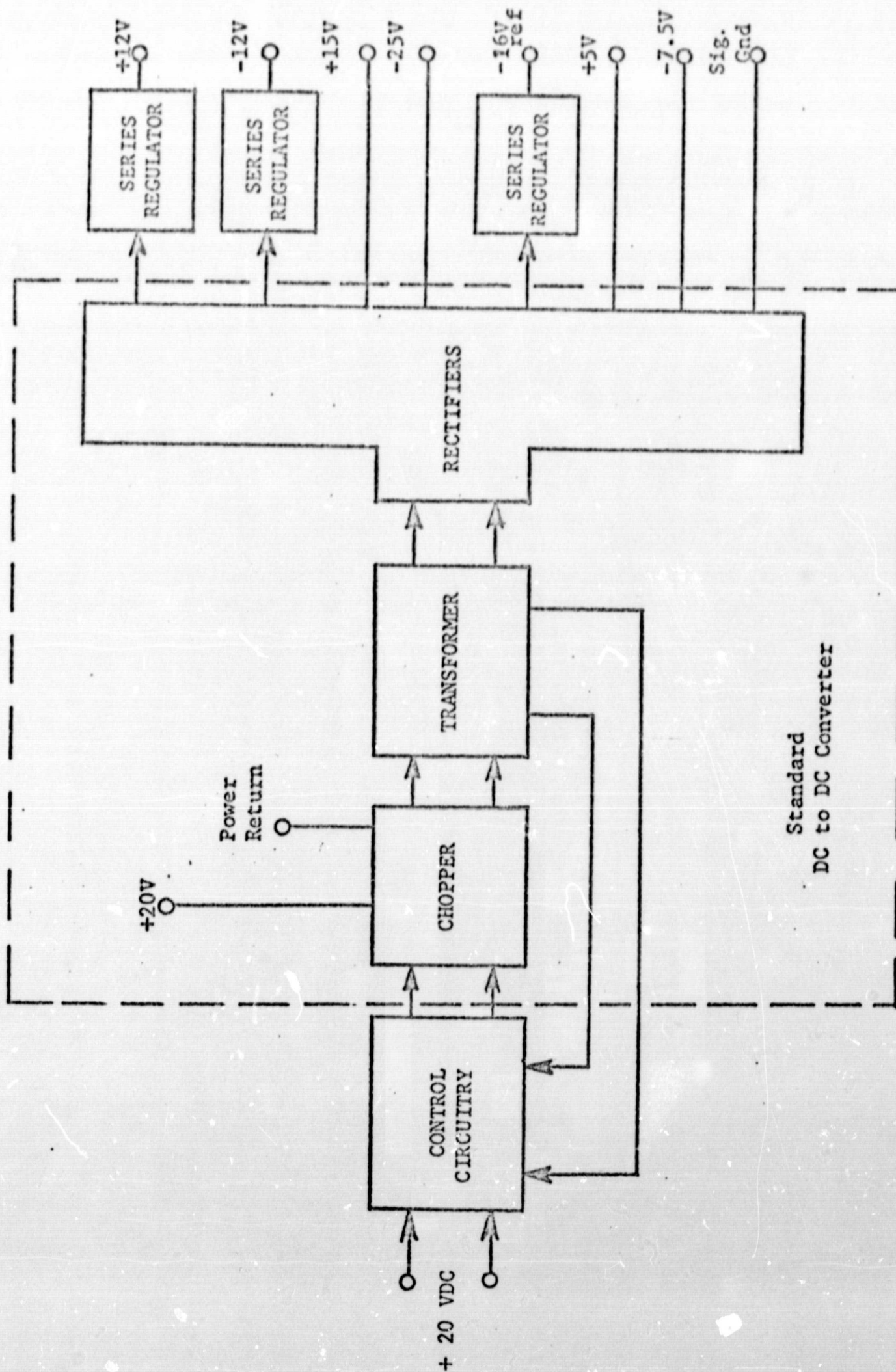


Figure 3-15. Low Voltage Power Supply Block Diagram

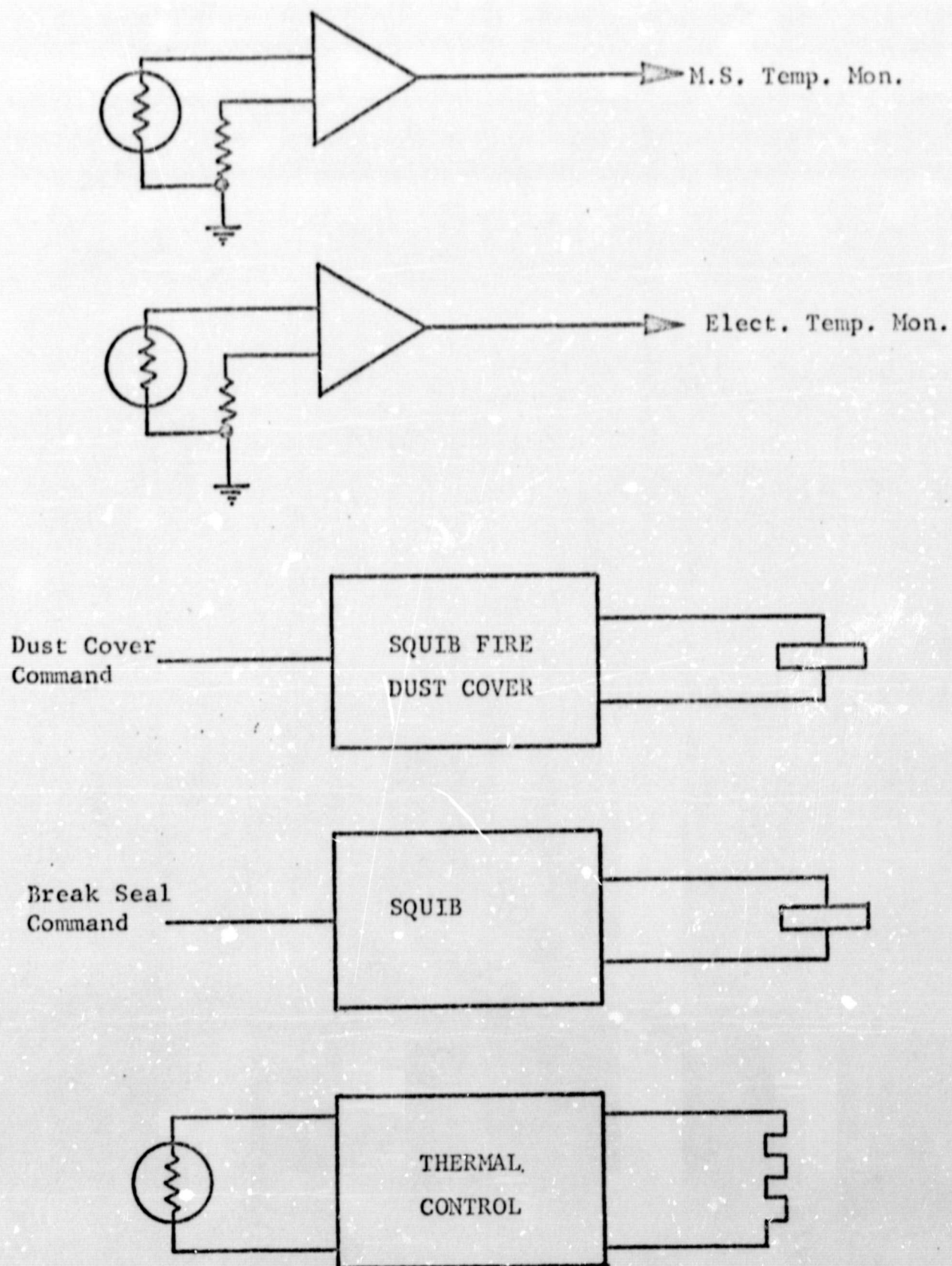


Figure 3-16. Thermal Control And Squib Firing Black Diagram

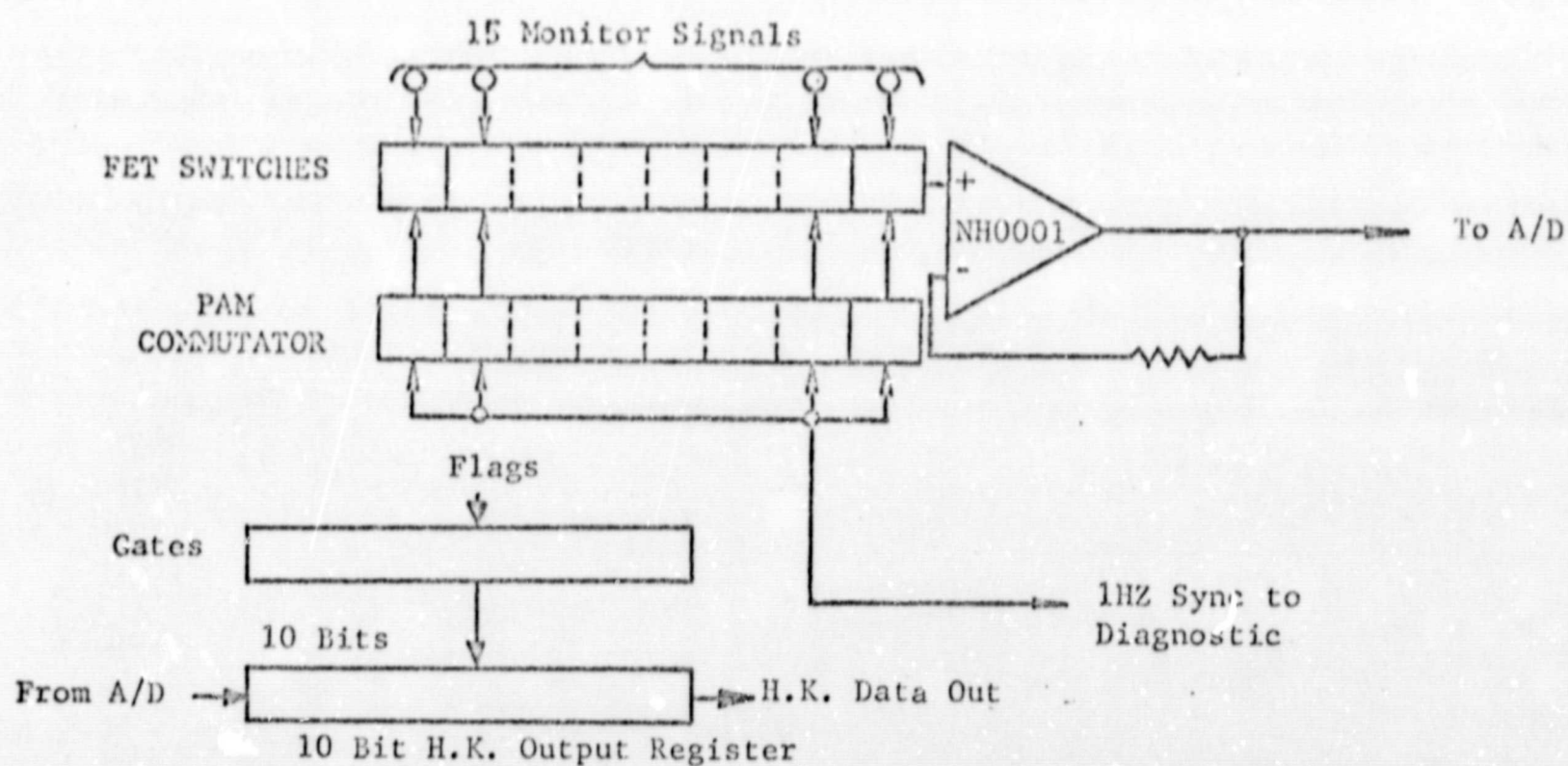
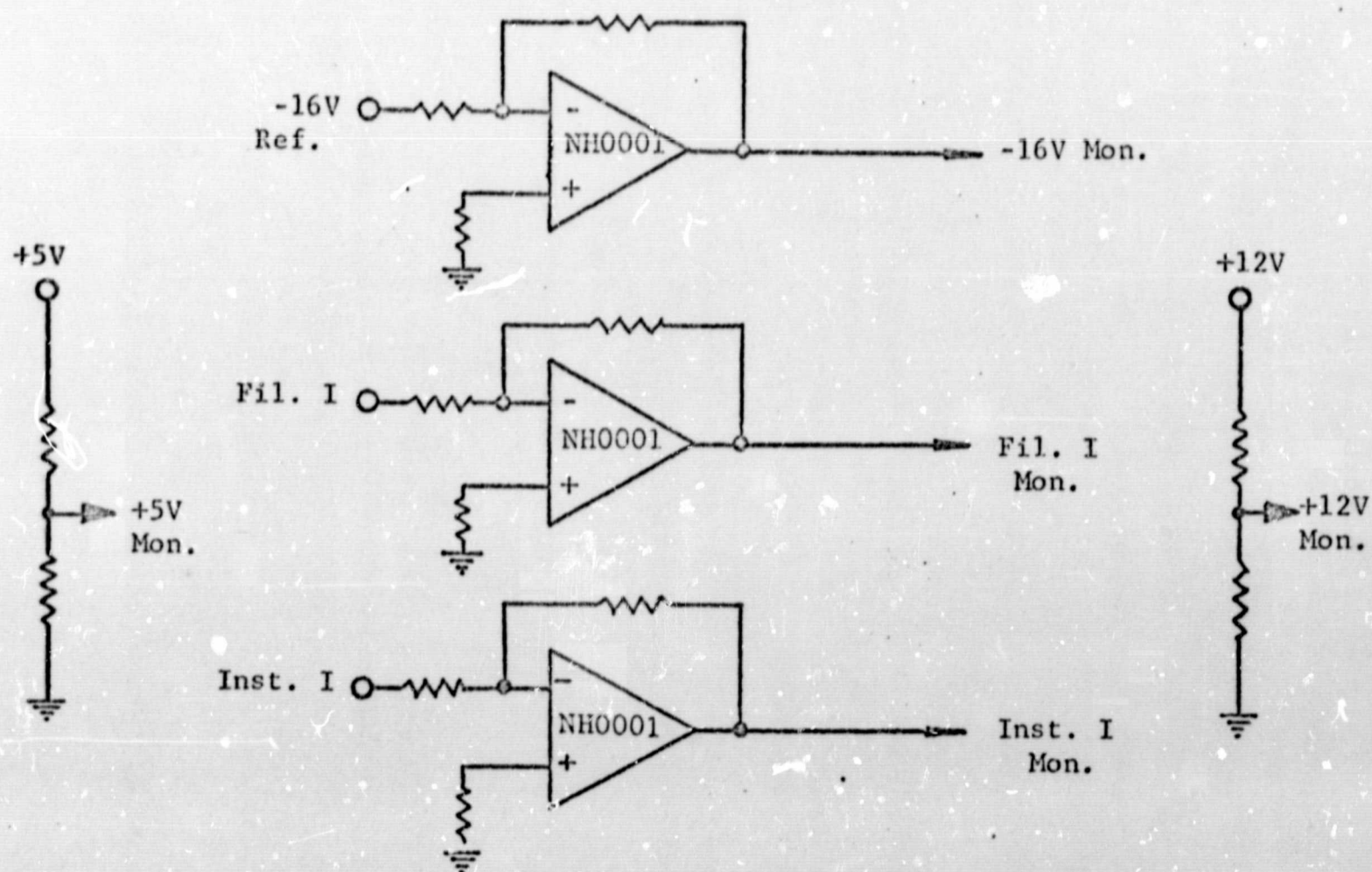


Figure 3-17. Housekeeping Multiplexer Block Diagram

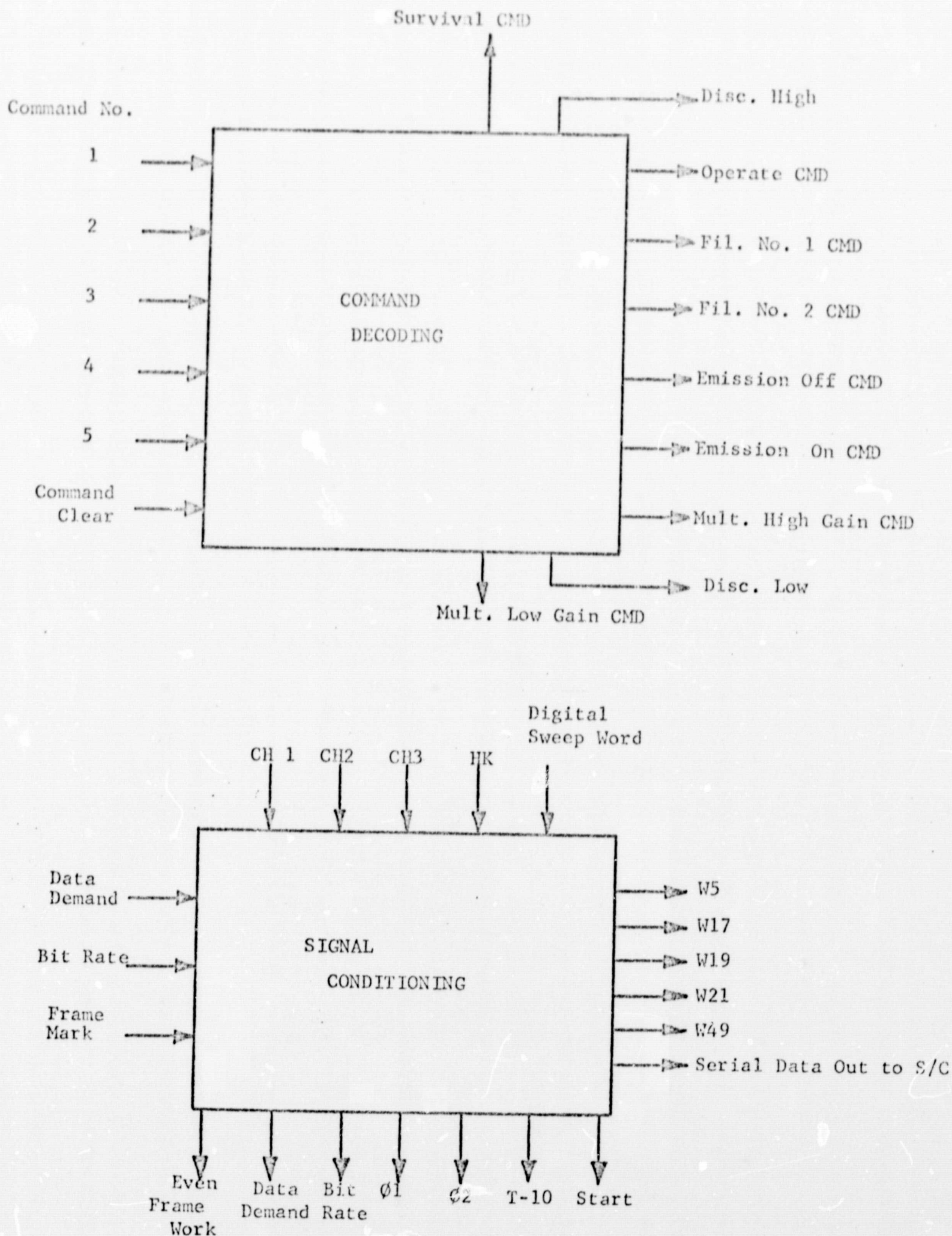


Figure 3-18. Data Control and Signal Conditioning

B. GROUND SUPPORT EQUIPMENT (GSE)

The purpose of this section of the report is to acquaint the reader with the technical details of the Ground Support Equipment (GSE) Console Unit as a part of the UTD Mass Spectrometer.

The GSE Console Unit has the capability of providing power and stimuli to the Mass Spectrometer. It also provides a monitoring and data recording capability.

1. Design Specifications

a. Electrical

The UTD-GSE unit interfaces electrically with the Mass Spectrometer.

- (1) AC Power and Input - The UTD-GSE Unit has the following AC power requirements:

Voltage: 120 volts + 3%, -10%, single-phase, 3-wire.

Frequency: 60 $\pm$ 1Hz

Harmonic Content: 3% RMS maximum

Peak Power: 20 amps

- (2) Signal Interface with Mass Spectrometer - The Console GSE interfaces with the CS connector of the Mass Spectrometer.

b. Mechanical

The mechanical characteristics of the UTD-GSE Unit are as described in the following paragraphs.

- (3) Physical Properties - The Console GSE is housed in an enclosure having the following outline dimensions:

Height:	36 inches maximum
Width:	22 inches maximum
Depth:	22 inches maximum
Weight:	200 pounds maximum

2. Requirements

The Console GSE will provide all electrical power, stimuli and communication signals required to operate the Mass Spectrometer in each of its modes.

- (4) Power - The Console GSE will provide electrical power to the Mass Spectrometer via the CS connector (J1).

The GSE provides the following basic powering capability at the CS connector:

Voltage:	36 VDC maximum, 27.5 VDC nominal
Current:	1.5 amperes maximum, 0.75 amperes nominal
Voltage Control:	0V to 36 VDC, 10 turns
Meters:	Voltage and current
Line Regulation:	0.005%
Load Regulation:	0.01%
Protection:	Current limiting and overvoltage
Model:	KEPCO CK36-1.5M power supply

- (5) Command and Control - The console GSE provides all of the Central Station functions.

In addition, the console GSE provides other functions which are desirable for checkout and test operations including diagnostic capability.

Commands - The following commands are provided:

<u>Command No.</u>	<u>Command Generated</u>	<u>Command No.</u>	<u>Command Generated</u>
1, 2 & 6	Survival	4, 5 & 6	Multiplier LO
1, 3 & 6	Operate	6	Command Clear
1, 4 & 6	Discriminator HI	7 & 6	Dust Cover
1, 5 & 6	Discriminator LO	8 & 6	Breakseal
2, 3 & 6	Filament #1		
2, 4 & 6	Filament #2		
2, 5 & 6	Multiplier HI		
3, 4 & 6	Emission OFF		
3, 5 & 6	Emission ON		

- (6) Data Display - The Console GSE provides decimal and binary display of the data work from the Mass Spectrometer switch. Status displays are by lamp indicator. Analog data are displayed in decimal form on the DVM. Lamps are provided to verify the instrument interface with commands.
- (7) Logic Unit - The Console GSE provides all of the digital logic to the Mass Spectrometer in such fashion as to essentially duplicate the function to be provided by the Central Station. The Logic Unit is constructed from commercial logic cards manufactured by Computer Controls Company. The Logic Unit pro-

vides the following functions:

(a) Data Word Enable Gate.

The Logic Unit generates and provides three synchronized word gates of 10-bit duration to the experiment. The word gates will occur at a 10-cps rate. The three word enable gates may be consecutive or separated by a multiple of 8 bits. The format is fixed to duplicate the assignment of the Central Station. The word enable gates appear on separate lines.

(b) Data Shift Clock.

A data shift clock is provided synchronous with each enable word gate. Each series of shift clock pulses contains 10 shift pulses. The shift pulse coincidence with the first bit is omitted. The first shift occurs at the start of the second bit period.

(c) Data Decompression.

The data processor provides logic to decode the compressed 10-bit data word from each ion counter channel into 4 code bits and 6 data bits.

(d) Binary to Decimal Conversion.

Each 10-bit binary data word is converted to binary coded decimal and made available to the data output register. The data output register provides the circuits to interface with the printer and the lamp display.

- (8) Data Printing Equipment - The Console GSE prints on paper tape the results of the data processor operations. Printing originates from a Franklin Printer Model 1630D-16-6A16. The printer prints on command from the data processor at a rate of 20 lines per second. The print format is as follows:

The analog printout, from the housekeeping updates at a 1 cps rate.

(a) Print Format:

<u>Columns</u>	<u>Information</u>
1	Housekeeping
2	Digital Sweep
3	Data
4	Data
5	Data

(b) Printer Characteristics:

Maximum Printing Speed	30 lines/sec
Print Drum Type	6A16 standard
Print Columns	16 columns
Marking System	Inked ribbons
	Fan fold paper
Finish	Standard commercial
Power Requirement	110 VAC, 60 Hz
Print Logic	8-4-2-1 "1" state position
Logic Levels	
"1"	4.0 VDC $\pm$ 1.5 VDC
"0"	0, 0, +.5, -0.0 VDC

Print Command

Same as above

Output Gate

Same as above

(9) Digital Voltmeter - A DVM whose principal function is to monitor the analog housekeeping signal is provided as a part of the Console GSE unit.

(10) DVM Characteristics - The DVM has built-in systems capability.

The DVM has the following characteristics:

Ranges	10V, 100V, and 1000V
Accuracy	$\pm(0.05\%$ of reading + 0.001% of range) 24 hours; $23^{\circ}\text{C} \pm 1^{\circ}\text{C} \pm (0.01\%$ of reading + 0.003% of range) 90 days.
Input Impedance	10^{10} ohms, 10V range 10^7 ohms, 100V and 1000V ranges
Speed	25 ms max unfiltered 500 ms max filtered
Maximum Data Range	80 ms unfiltered
Data Output	DTL and TTL compatible, fully isolated.

(11) Analog Housekeeping Functions - The analog housekeeping data format is given in Appendix A.

IV. PERFORMANCE TEST RESULTS

A Prototype Acceptance Test Procedure has been written and is attached as Appendix A. This procedure is used for testing the functional operation of the instrument in the Ultra-High Vacuum Chamber at UTD and during the environmental tests at MSC. The latter are discussed in Section V.

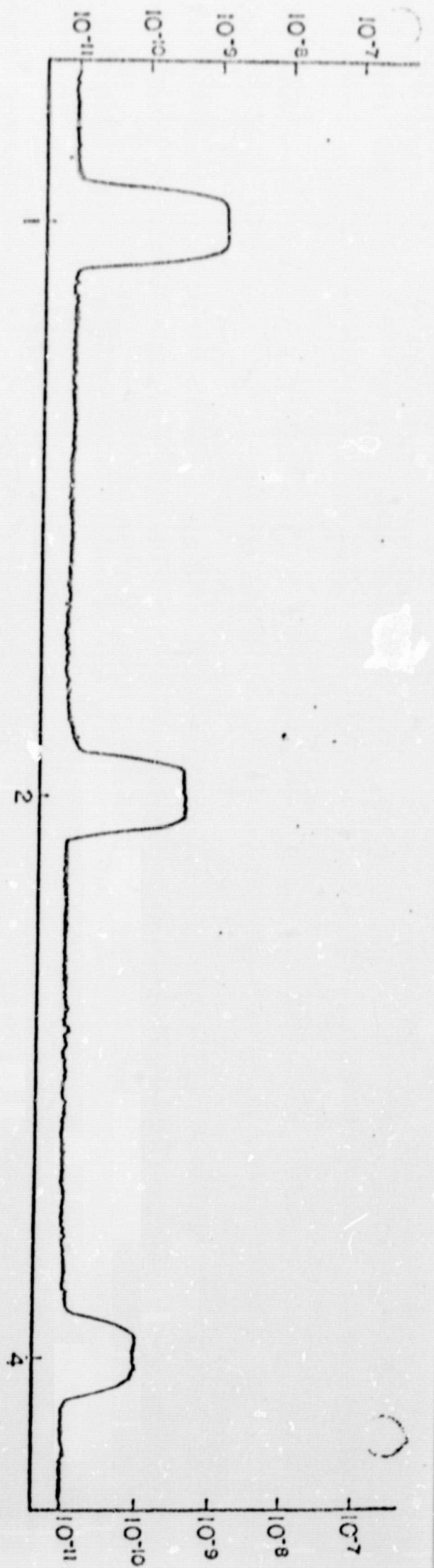
The tests conducted at UTD consisted of an operational checkout test to ensure proper operation of the instrument. The analyzer section was initially tested in the vacuum chamber utilizing electronics mounted external to the chamber to facilitate adjustment of the variable parameters. Mass spectra were taken which are shown in Figure 4-1 for the three mass ranges of the instrument. The high mass range extends to mass 160 amu but only the portion to mass 86 is shown in the figure. The mass resolution is such as to clearly separate mass 3 from 4 in the low mass channel, 40 from 41 in the intermediate mass channel, and 112 from 113 in the high mass channel. This resolution is sufficient to prevent more than a 1 percent interference between the Xenon isotopes in the 130 amu mass range; also, there is less than 1 part in 300 of the mass 40 peak at mass 39. The figures are tracings from an analog output from the instrument, the ordinate being a log scale. The amplitude scale is shown at the left. In lunar operation, the data collection will be in digital form, that being the number of counts obtained per voltage step of the high voltage sweep circuit (see Section III). A sample printout is shown in Figure 4-2. The number of ions counted on each voltage step is listed as a function of time (time after sweep start) indicated by a flag, being related to mass number. One count per step (nominally taken

to be 1 second) represents a sensitivity of 1×10^{-15} torr. Ten counts per step, signal to noise ratio of 2 or 3, represents a usable sensitivity of 10^{-14} torr. The background counter rate is usually from 0 to 3 counts per step.

The entire prototype instrument was operated in the vacuum chamber 24 hours after pumping was initiated. With an ambient pressure of 10^{-7} torr the instrument electronics exhibited no tendency toward high voltage arcing or corona problems. This test proved that adequate outgassing parts were designed into the electronics package to prevent such problems.

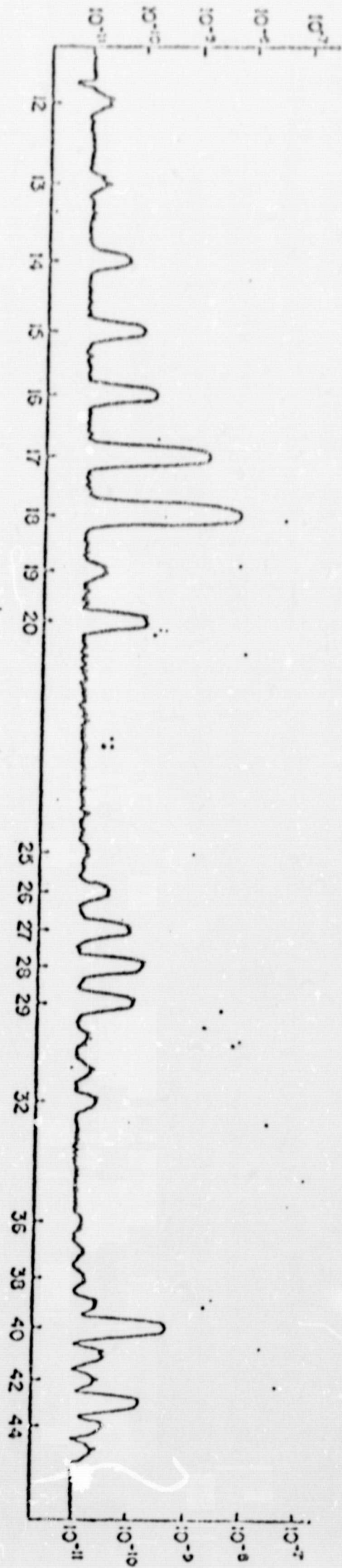
Future tests of the Mass Spectrometer include participation in the planned comparison tests between three proposed Lunar Mass Spectrometers to be conducted at the JPL Molsink in the fall of 1970. The purpose of these tests is to compare the operation of these instruments at very low pressures and to study their sensitivity to various gases.

ION CURRENT (AMPS)

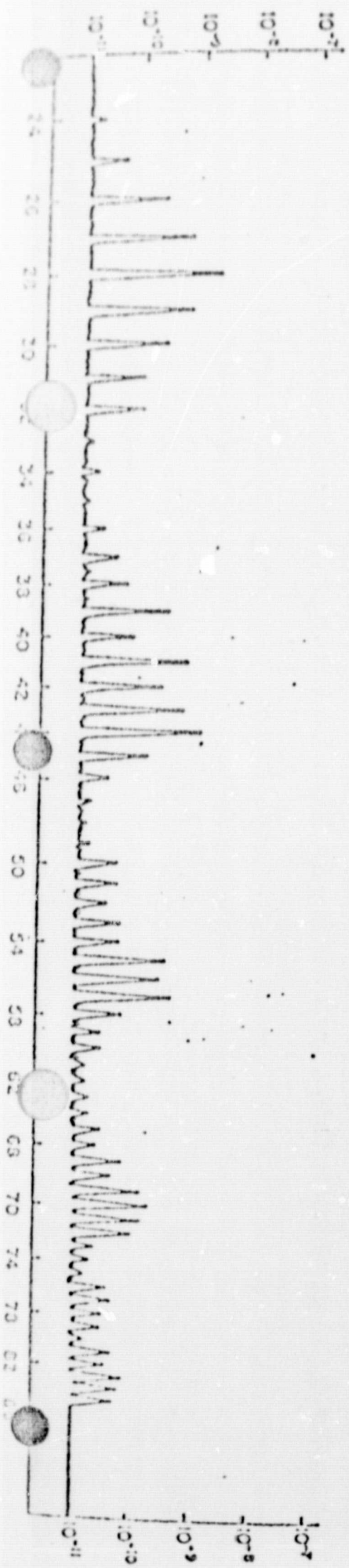


LOW MASS CHANNEL

ION CURRENT (AMPS)



ION CURRENT (AMPS)



0 0 0 0 4		0 0 0 0 2		0 0 0 0 2
0 0 0 0 3		0 0 0 0 2		0 0 0 0 0
0 0 0 0 1		0 0 0 0 0		0 0 0 0 0
0 0 0 0 2		0 0 0 6 8		0 0 0 2 8
0 0 0 0 3		0 3 0 6 2		0 0 1 1 6
0 0 0 0 2		1 5 4 4 9	19	0 0 <u>1 4 6</u>
0 0 1 8 8	17	<u>1 9 3 7 2</u>		0 0 <u>1 4 5</u>
0 3 9 1 5		1 8 4 9 3		0 0 0 6 3
0 6 3 2 9		0 9 5 4 0		0 0 0 0 7
<u>0 6 4 0 2</u>		0 0 4 2 8		0 0 0 0 0
0 2 8 1 3		0 0 0 0 2		0 0 0 0 3
0 0 0 6 7		0 0 0 0 1		0 0 0 0 0
0 0 5 3 0		0 0 0 0 2		0 0 0 0 0
0 0 0 0 2		0 0 0 0 6		0 0 0 0 1
0 0 0 0 1		0 0 0 0 1		0 0 0 0 0
0 0 0 0 4		0 0 0 0 2		0 0 0 0 0
0 0 0 0 3		0 0 0 0 6		0 0 0 0 1
0 0 0 0 1		0 0 0 0 1		0 0 0 0 2
0 0 0 0 1		0 0 0 0 3		0 0 0 0 1
0 0 0 0 1		0 0 0 0 2		0 0 0 0 3
0 0 0 0 1		0 0 0 0 0		0 0 0 1 0
0 0 0 0 0		0 0 0 0 1		0 0 0 0 4
0 0 0 0 2		0 0 0 0 2		0 0 0 0 1
0 0 0 1 0		0 0 0 0 4		0 0 0 0 2
0 0 0 1 6		0 0 0 0 0		0 0 0 0 4
0 0 0 1 8		0 0 0 0 0		0 0 0 0 3
0 0 0 0 6		0 0 0 0 3		0 0 0 0 2
0 0 0 0 1		0 0 0 0 1		0 0 0 0 3
0 0 0 0 1		0 0 0 0 0		0 0 0 0 1
0 0 0 0 1		0 0 0 0 1		0 0 0 0 2
0 0 0 0 1		0 0 0 0 1		3 0 7 0 4
0 0 0 0 0		0 0 0 0 4		2 7 2 6 4
0 0 0 0 0		0 0 1 3 7		6 3 5 3 1
0 0 0 0 3		0 4 5 3 7	18	<u>6 6 4 7 0</u>
0 0 0 0 2		1 0 7 5 2		6 6 9 2 0
0 0 0 0 0	16	<u>1 3 0 0 1</u>		0 9 3 8 8
0 0 0 0 1		0 9 5 8 5		0 0 0 8 3
0 0 1 0 9		0 2 8 0 9		0 0 0 1 0
0 1 8 3 2		0 0 1 4 1		0 0 1 1 0
<u>0 3 5 0 3</u>		0 0 0 0 2		0 0 0 5 3
0 8 4 6 4		0 0 0 0 0		0 0 0 0 5
0 1 3 7 7		0 0 0 0 1		0 0 0 0 5
0 0 0 5 4		0 0 0 0 2		0 0 0 1 1
0 0 0 0 2		0 0 0 0 1		0 0 0 0 1
0 0 0 0 2		0 0 0 0 1		0 0 0 0 0
0 0 0 0 0		0 0 0 0 0		0 0 0 0 1
0 0 0 0 1		0 0 0 0 2		0 0 0 1 2
0 0 0 0 3		0 0 0 0 1		0 0 0 1 8
0 0 0 0 0		0 0 0 0 0		0 0 0 1 8
0 0 0 0 0		0 0 0 0 2		0 0 0 0 8
0 0 0 0 3		0 0 0 0 2		0 0 0 0 1
0 0 0 0 2		0 0 0 0 1		0 0 0 0 1
0 0 0 0 0		0 0 0 0 2		0 0 0 0 4
0 0 0 0 4		0 0 0 0 1		0 0 0 0 1

Figure 4-2. Digital Mass Spectrom AMU Printout

V. ENVIRONMENTAL TEST RESULTS

A. STRUCTURAL TESTS

A structural model of the Mass Spectrometer was constructed containing weighted PC boards to simulate actual weights, a dummy analyzer tube and an actual magnet. The Environmental Test Specification (ERD-SM-1001) to which the instrument was subjected is included as Appendix B. The structural model successfully underwent a 3-axis vibration test to ALSEP qualification levels on May 23, 1969. A report on the test (Document No. 644D.41.12) is attached as Appendix C. In a previous vibration test a failure occurred in the horizontal shake test in the electronics package. The two sets of four printed circuit cards mounted on stand-offs from the radiator plate broke loose due to a shearing of the studs on which they were mounted. This problem was corrected and the subsequent test proved the system acceptable. The prototype Mass Spectrometer was subjected to the same test as the structural model on January 9, 1970, with the result that no structural problems occurred and the instrument was operational before and after the test. As a result of these tests, the structural design of both the mechanical hardware and the electronics packaging is considered to be proven adequate for flight on Apollo missions.

B. THERMAL VACUUM TESTS

A thermal model of the Mass Spectrometer was constructed using the structural model fitted with PC boards. These PC boards were to dissipate the design power of each electronics subassembly and were adequately fitted with thermocouples. A thermal vacuum test simulating both lunar night and lunar day was conducted in a vacuum chamber at MSC on the Thermal Model in June 1969, according to the test specifications, ERD-SM-1001. During the cold test it was found that in a survival mode -- heater power only --

6 watts were required to maintain the coldest point in the electronics section at -75°F . This is barely within specifications of survival of electronic components. With no heater power and 10.8 watts of experiment power, the coldest point was -17°F which is barely tolerable. The addition of 6 watts of heater power raised the temperature to 35°F which is quite acceptable. During the hot test with experiment power on, 10.8 watts, the hottest point in the electronics area was 81°F , well within specifications of electronics components. No major problems resulted from these tests and the thermal design of the package is considered adequate. However, if all of the temperatures were increased 20 to 25°F , they would lie more within the design ranges. This may be accomplished by masking off a portion of the mirrors on the radiator plate. A report of the test results is attached as Appendix D.

A thermal vacuum test of the prototype Mass Spectrometer was conducted in January 1970, to the same test specifications as the thermal model. A number of thermocouples were attached to key parts of the electronics modules and the analyzer section. A plot of equilibrium temperatures for various power input conditions is shown in Figure 5-1. From the figure it is seen that the coldest temperature experienced by the baseplate with heater power only on is -30°F while with the electronics power on it is $+15^{\circ}\text{F}$. The warmest temperature seen is $+80^{\circ}\text{F}$. The worst case electronics temperatures are -20°F , $+40^{\circ}\text{F}$, and $+100^{\circ}\text{F}$, respectively. Again, the electronics appears to be well protected by the thermal control system. The baseplate temperature excursions are considerably larger, -180°F to $+190^{\circ}\text{F}$, but there are no components in this region that are temperature sensitive.

These tests indicate that the thermal design of the Mass Spectrometer is sufficient to protect the instrument on the lunar surface and ensure its workability through many lunar days.

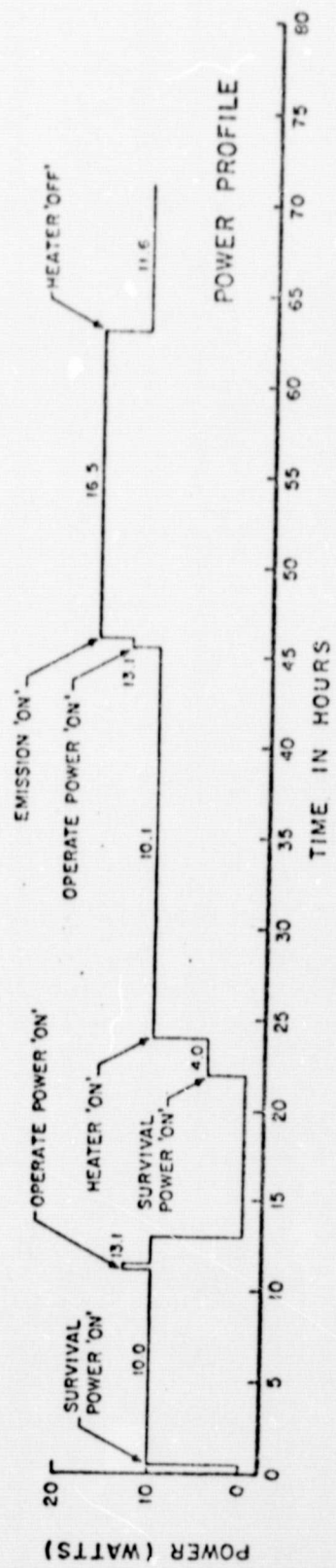
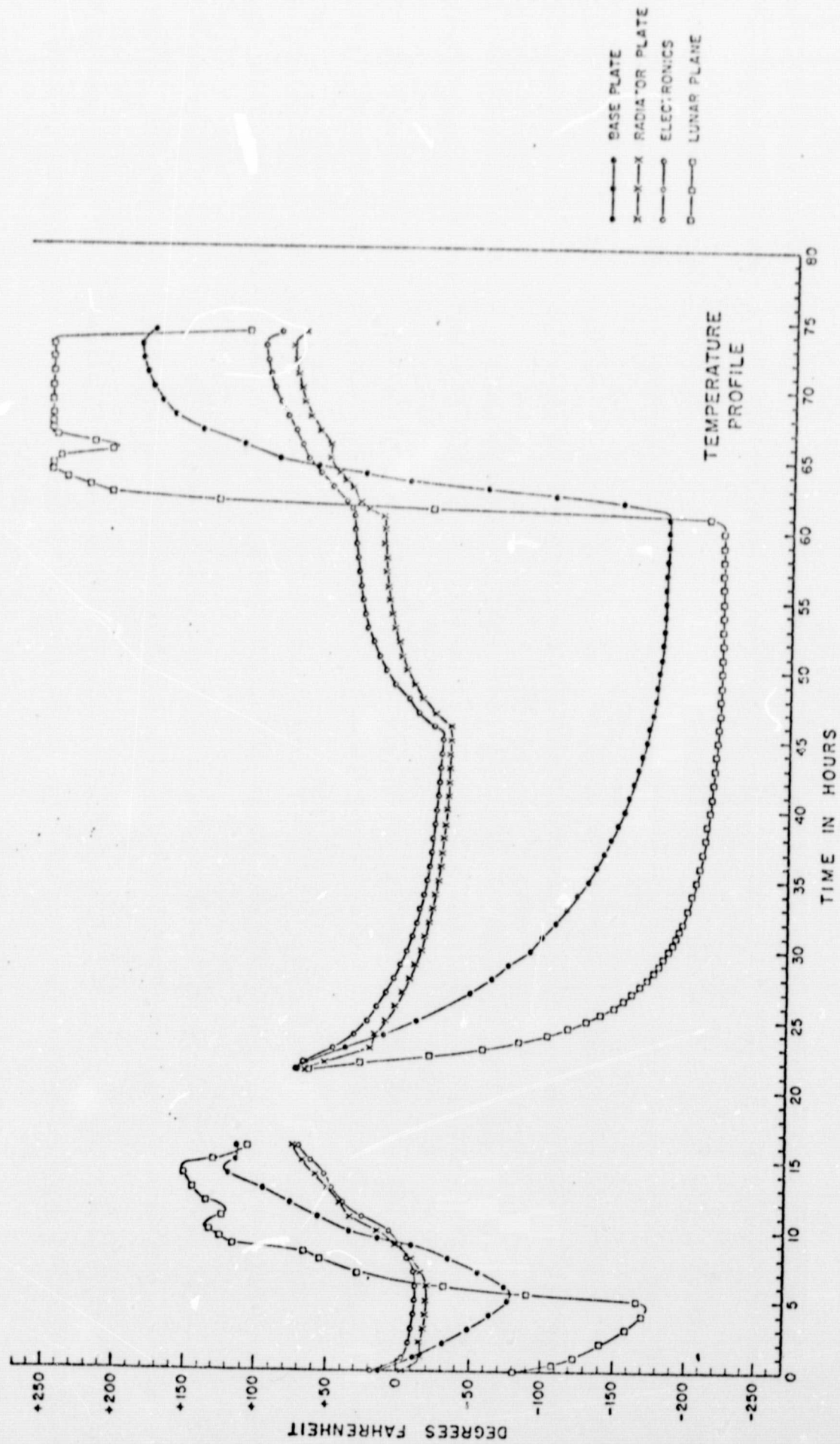


Figure 5-1. Gela Thermal Vacuum

APPENDIX A

GAS ANALYZER FOR LUNAR ATMOSPHERE (GALA)

PROTOTYPE ACCEPTANCE TEST PROCEDURE

GAS ANALYZER FOR LUNAR ATMOSPHERE (GALA)

PROTOTYPE ACCEPTANCE TEST PROCEDURE

GAS ANALYZER FOR LUNAR ATMOSPHERE (GALA)

PROTOTYPE ACCEPTANCE TEST PROCEDURE

1.0 Objective:

The objective of this test procedure is to verify the functional and mechanical acceptance of the GALA package for a future APOLLO flight.

2.0 Scope:

The test procedure is to provide assurance of the overall system compatability with the APOLLO scientific instrument requirements.

3.0 Gas Analyzer for Lunar Atmosphere Operation:

3.1 Inputs from Data Processor:

The GALA package requires three (3) timing and control signals, plus eight (8) up-link commands from the Data Processor to perform the experimental measurements. These signals are discussed below.

3.1.1 The three (3) timing and control signals are used to process and output to the Data Processor five (5) 10-bit digital data words.

The three (3) input signals are:

- A. Frame Mark
- B. Data Demand
- C. Shift Clock (Bit rate)

For a description of the above mentioned signals see attached memorandum data January 16, 1968.

3.1.2 The eight (8) up-link commands are used to establish operational modes of the experiments to provide flexibility in performing the intended measurement.

3.1.2.1 Eight (8) commands are utilized to perform thirteen (13) separate operations; a command decoder is used to achieve this.

<u>Command No.</u>	<u>Command Generated</u>
1, 2 & 6	Survival
1, 3 & 6	Operate
1, 4 & 6	Discriminator HI
1, 5 & 6	Discriminator LO
2, 3 & 6	Filament #1
2, 4 & 6	Filament #2

(Gas Analyzer for Lunar Atmosphere (GALA) Prototype Acceptance Test Procedure)

<u>Command No.</u>	<u>Command Generated</u>
2, 5 & 6	Multiplier HI
3, 4 & 6	Emission OFF
3, 5 & 6	Emission ON
4, 5 & 6	Multiplier LO
6	Command Clear
7 & 6	Dust Cover
8 & 6	Breakseal

Command 6 follows every command generated, example: To go to the operate mode send commands 1, 3 & 6.

3.1.2.2 Survival Mode:

This is a low power mode of operation. The following circuits have full power applied to them:

1. Switching Pre-regulator
2. Low Voltage Power Supply
3. Data Control and Signal Conditioning Card
4. Thermal Control and Squib Firing Ckts. Card

All other circuitry are without power.

3.1.2.3 Operate Mode:

This is the normal mode of operation, however, the system is not fully operative unless the Emission is ON.

3.1.2.4 Discriminator HI-LO:

The HI-LO operation is needed to control the discriminator setting. The discriminator follows the charge sensitive pre-amplifier.

3.1.2.5 Filament #1, #2:

This system has two (2) separate filaments for redundancy in the ion source, selectable by command.

3.1.2.6 Multiplier HI-LO:

The gain of the three (3) multipliers can be changed by varying the high voltage applied to them. Two (2) separate gain settings are possible through the command system.

3.1.2.7 Emission ON-OFF:

Through the use of commands the Emission Control Card can be turned ON or OFF.

(Gas Analyzer for Lunar Atmosphere (GALA) Prototype Acceptance Test Procedure)

3.1.2.8 Breakseal:

This command, when sent, will blow the squibs in the can cutter and the entrance will be exposed to the outside environment.

3.1.2.9 Dust Cover:

This command, when sent, will blow the squib and the dust cover will be released. This exposes the mirrors to the sunlight.

3.1.2.10 Command Clear:

This command is sent with every command in the command generated list (3.2.2). This clears the J-K flip flops in the command decoder.

3.2 GALA Outputs:

The GALA package has five (5) outputs all of which are ten (10) bit words. Three (3) are used to carry data from the three (3) channels of the mass spectrometer. One ten (10) bit word is the status of the digital sweep generator. The last word is used for housekeeping and flags.

3.2.1 Each of the three (3) data words has the format as shown in Figure 1, which consists of the 6-bits of the 21-bit counter and the four (4) bits of the shift counter.

3.2.2 Housekeeping Functions:

All housekeeping functions are sub-commutated. A fifteen (15) position commutator¹⁵ stepped through by the frame mark pulse that is generated within the experiment.

Housekeeping Data Assignments:

<u>Position No.</u>	<u>H. K. Data</u>
1	-12V
2	+ 5V
3	+12V
4	Spare
5	A/D Calibrate
6	Filament Current
7	Instrument Current

(Gas Analyzer for Lunar Atmosphere (GALA) Prototype Acceptance Test Procedure)

<u>Position No.</u>	<u>H. K. Data</u>
8	H. V. Mult. Monitor
9	H. V. Sweep Monitor
10	Temp. #1 (Electronics)
11	Temp. #2 (M.S.)
12	Spare
13	Flags
14	Spare
15	-16V Ref.

The thirteenth (13th) position is the flag word.

Figure 2 shows the digital format. of the Housekeeping FCNS.

- 3.2.2.1 Below is a tabulation of the flag assignments going from right to left (see Figure 3) as these bits would appear on the data line.

<u>Bit Position</u>	<u>Function</u>	<u>"1" Represents</u>
10 (MSB)	H. K. Multiplexer Pos #1	Pos #1
9	Digital Sweep Start	Start
8	Spare	----
7	Discriminator HI-LO	HI
6	Filament #1 - #2	#1
5	Emission HI-LO	HI
4	Emission ON-OFF	ON
3	Spare	----
2	Spare	----
1 (LSB)	Multiplier HI-LO	HI

A zero ("0") will represent a spare.

Figure 3 shows the bit assignment.

- 4.0 Experiment Test Set Operation
- 4.1 The GALA Experiment Test Set (ETS) provides the input signals, power, visual readout, and data processing capabilities during bench testing.
- 4.2 ETS

The ETS consists of the following Equipment;

- 1) Digital Voltmeter (DVM)
- 2) Digital logic System
- 3) 12 column Printer
- 4) Power Supply
- 5) Control Panel with data display.

4.3

ETS Digital Data Display

The digital data consists of five ten bit words which are printed out by the twelve (12) column printer. Column 1 which is numbered from 1 to 5 indicates the word number.

Word numbers 3, 4, 5, are the three Mass spectrometer channel data words; which are located in columns 6 thru 12 inclusive. These are read out in decimal.

Word 2 represents the status of the digital sweep counter in the high voltage sweep control circuit. It is read out as a decimal number and is located in columns 9 thru 12 inclusive.

Multiplexer Position	HK. Function	Normal Reading.		Tolerance
1	-12V	125		± 5
2	+5V	127		± 20
3	+12V	140		± 5
4	GND	000		---
5	A/D CAL	155		± 3
6	Fil I	000		---
7	Inst. I	000		---
8	Mult H. V.	Hi Lo 181 169		± 3
9	Sweep H. V.	000	-204	---
10	T ₁	000		
11	T ₂	000		---
12	Spare	000		---
13	Flags	---		---
14	Spare	000		---
15	-16V	149		± 3

APPENDIX B
ENVIRONMENTAL TEST SPECIFICATION
FOR THE
MASS SPECTROMETER

MASS SPECTROMETER EXPERIMENT

for

EXTENDED ALSEP

ENVIRONMENTAL TEST SPECIFICATION

for the

MASS SPECTROMETER

ERD-SM-1001

NASA-Manned Spacecraft Center

Earth Resources Division

TF4

5-5-69

B-2

1.9 SCOPE

1.1 General

This specification establishes environmental test requirements for the Mass Spectrometer Experiment.

1.2 Applicability

Decisions regarding the applicability of the requirements set forth in this specification shall be made by the Earth Resources Division (TF4). The environmental extremes shown in this specification are for qualification units only.

1.3 Objectives

The objectives of the tests outlined in this specification are to gain assurance that the Mass Spectrometer will survive all of the environmental loads to which it will be exposed during transportation, launch, boost, and lunar descent, and that it will function properly throughout its intended life.

2.0 APPLICABLE DOCUMENTS

2.1 ICS 314103 Bendix ICS for ALSEP/LSM

2.2 LED-520-1D Grumman Aircraft Engineering Corporation

2.3 MIL-STD 810-A

3.0 TEST LOCATION

All tests in this specification shall be conducted at NASA Manned Spacecraft Center, Houston, Texas or at a testing laboratory specified by the Earth Resources Division.

3.1 Test Facilities

3.1.1 General

The equipment used in conducting the tests specified herein shall be capable of producing and maintaining the required conditions with the Mass Spectrometer installed in a non-operating state.

3.1.2 Conditions for the Test Area

Laboratory conditions for conducting operational checkout prior to and/or following each environmental test shall be maintained as follows:

- (1) Temperature: $25^{\circ}\text{C} \pm 5^{\circ}\text{C}$,
- (2) Relative Humidity: 70% or less.

3.1.3 Measuring, Control, and Recording Equipment

- (1) All measurements of the environmental conditions shall be made with instruments which are appropriate for the test being conducted. The accuracy of the measurements shall be listed and made available to the Earth Resources Division One (1) week prior to start of the tests. The list shall include the following: manufacturer and model number, accuracy of the instrument, and data of calibration. The calibrations shall be traceable to National Bureau of Standards.
- (2) Control of the extremes shall be accomplished within the tolerance specified below exclusive of the measuring instrument tolerances.
 - (a) Temperature: Plus or minus 2°F after stabilization
 - (b) Sinusoidal Vibration: Plus or minus 10% for the applied 20-60 and 60-100 Hz frequency ranges.
 - (c) Random Vibration: The specified power spectral density shall be equalized to within ± 3 db over the entire frequency range.
 - (d) Thermal Vacuum: Temperature - $\pm 2^{\circ}\text{C}$ after stabilization.

- (3) Recording instruments shall be used so that a permanent record of all applied loads can be made available to the project engineer for review and approval prior to acceptance of the specimen tested. Recordings should be made on paper with strip chart recorders and/or X-Y plotters if possible.

4.0 EVALUATION OF TEST SPECIMEN

The test specimen shall be subjected to an operational test prior to each phase of environmental testing in order to determine at which point failure occurs, should a failure occur. In the event of a failure the test specimen shall be investigated and the cause of the failure determined by cognizant personnel. A report shall then be submitted to the Earth Resources Division for evaluation and they shall make a decision to either repair and proceed with the test or to review the failure with design personnel and submit a new specimen with corrective changes incorporated. Individual measurements to be made on the specimen at each test level shall be determined by the Earth Resources Division. In addition to the operational test a visual examination shall be made prior to each phase of environmental testing. Operational tests to be performed are as specified in Appendix 1 of this specification.

4.1 Waiver of Test Requirements

Although complete evaluation of flight experiments is desirable, due to a limited time element in the overall program some or all environmental tests may be waived by the Earth Resources Division on any units, if it is feasible to do so after reasonable assurance of reliable design has been established on qualification models.

5.0 ENVIRONMENTAL CONDITIONS

5.1 Sinusoidal Vibration

The Mass Spectrometer Experiment test specimen shall be rigidly attached to a test fixture, and the fixture attached to the vibration exciter. The specimen shall then be subjected to vibration as specified in Table I in each of three mutually perpendicular axis. For definition of X_L , Y_L , Z_L axis system see Figure 1. The specimen shall be visually examined and functionally tested prior to vibration along each axis to insure proper operation.

TABLE I

Frequency	"g" level	Duration
5-20 Hz	00.370 D.A.	One sweep at 1 octave/min.
20-60 Hz	7.15 $\pm$ 1.0 0-peak	
60-100 Hz	8.50 $\pm$ 1.0 0-peak	Decrease Frequency Only

5.2 Random Vibration

The Mass Spectrometer Experiment test specimen shall be rigidly attached to a test fixture, and the fixture attached to the vibration exciter. The specimen shall be subjected to the vibration as specified in Table II for a period of 5.0 minutes in each of three mutually perpendicular axis. The specimen shall be visually examined and functionally tested prior to vibration on each axis to insure proper performance.

TABLE II

Frequency (Hz)	Power Spectral Density
23-60	12 db/octave $\pm$ 1 db increase
60-150	0.387 g^2/Hz
150-530	12 db/octave $\pm$ 1 db decrease
530-2000	0.00185 g^2/Hz

5.3 Lunar Surface Temperature Simulations

The Mass Spectrometer Experiment test specimen shall be placed in a lunar surface simulation chamber in a deployed state with the survival power turned on.

The chamber shall then be pumped down to a pressure of at least 10^{-6} torr. The lunar surface temperature shall be approximately -300°F or with the temperature of the electronics package stabilized. The electronics package stabilization shall be determined by a one degree change per hour in the temperature.

The Mass Spectrometer test specimen shall continue to operate while the lunar surface plate temperature is increased to $+250^{\circ}\text{F}$ until stabilization of the electronics package (one degree change per hour).

The Mass Spectrometer Experiment test specimen shall be de-energized and the chamber pressure and temperature brought back to room ambient conditions.

6.3 TEST CONCLUSION

Upon completion of the above environmental task, the Mass Spectrometer shall be visually inspected for component damage. Following the visual inspection an extensive functional test shall be performed to insure performance within specified limits.

6.1 Test Report

A formal report shall be submitted within thirty days after completion of the test. The report shall contain the final analysis of all test data gathered during the test program.

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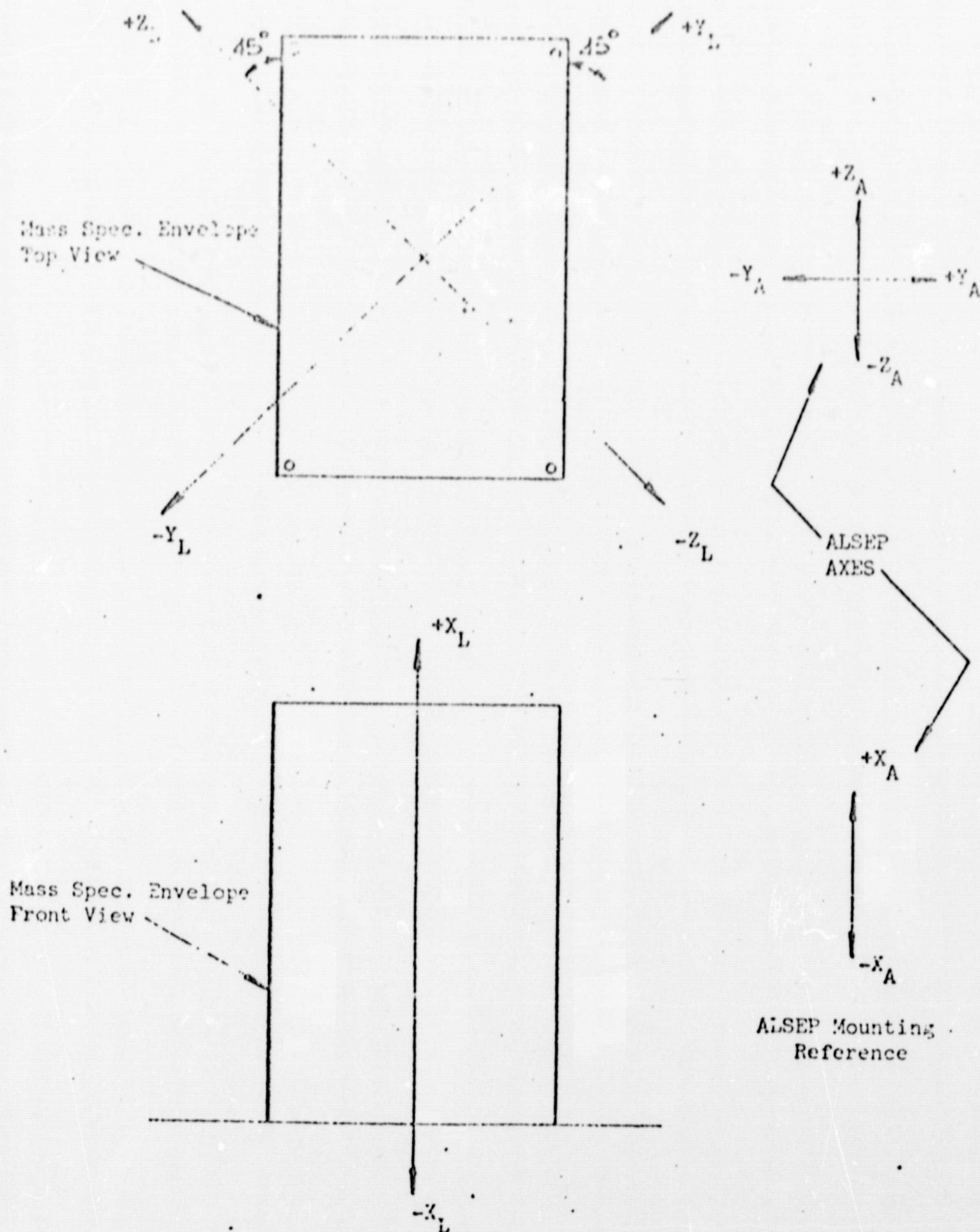


Figure 1
DEFINITION OF LM - ALSEP AXES

5/5/69

OUTLINE OF THERMAL/VACUUM
TEST
FOR
MASS SPECTROMETER

This test outline will apply to the thermal/vacuum test unit of the Mass Spectrometer (MS) for advanced Apollo Lunar Surface Experiments Package. The environmental test specification ERD-SM-1001 section 5.3 will be performed in its entirety in the following sequence:

- 1) Install the MS in the vacuum chamber with all interconnecting cables and thermal couples. (There will be approximately 6 cables for heater strips, heater resistors and platinum resistors, and approximately 50 T.C. cables.)
- 2) Perform electrical check for all cables. Provide read out on all T.C.
- 3) Close and pump chamber down.
- 4) Add liquid nitrogen to walls until reading equilibrium temperatures. (Time approximately 24 to 36 hours to equilibrium temperatures.)
- 5) Perform electrical tests simulating both survival mode and "full-up" operation of MS at lunar night conditions.
- 6) Turn on solar simulators with solar radiation normal to top (on solar mirrors) of Mass Spectrometer.
- 7) Reach equilibrium temperatures which record all T.C. read outs.
- 8) Perform electrical tests simulating "full-up" operation of MS at lunar noon conditions.

OUTLINE OF THERMAL/VACUUM TEST

FOR MASS SPECTROMETER

Page 2

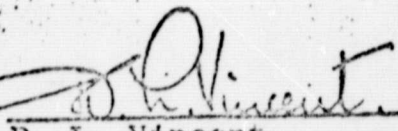
- 9) Record all chamber pressures.
- 10) Turn solar plane to 45° from normal and reach equilibrium temperatures.
- 11) Turn off solar simulators and bring chamber up to atmospheric pressures.

APPENDIX C
VIBRATION TEST RESULTS
FOR THE
MASS SPECTROMETER (GALA)
STRUCTURAL MODEL

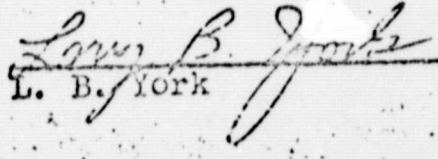
VIBRATION TEST RESULTS
FOR THE
MASS SPECTROMETER (GALA)
STRUCTURAL MODEL

LEC Document No. 644D.41.12

PREPARED BY:


D. L. Vincent

APPROVED BY:


L. B. York

NASA-MANNED SPACECRAFT CENTER

July 29, 1969

VIBRATION TEST RESULTS FOR THE
MASS SPECTROMETER (GALA) EXPERIMENT
STRUCTURAL MODEL

INTRODUCTION

On Monday, 19th May, 1969, the structural model of the Mass Spectrometer (GALA) Experiment was tested at the Space Electronics Systems Division, Environmental Test and Evaluation Section in Building 15.

The purpose of the vibration test was to show that the structure and packaging of the experiment were capable of satisfactorily surviving the specified vibration environment and that all structural items (such as the dust covers) were capable of fulfilling their function after exposure to that environment. Further, it was proposed to obtain some estimate of the dynamic envelope of the experiment when subjected to the specified vibration levels.

The structural model consisted of all structural components for the GALA, together with dust covers and release mechanism, P/C boards with component mass simulation, simulated sensor (supplied by Southwest Center for Advanced Studies, Dallas, Texas) and simulation of the ALSEP Central Station cable and reel. Figure 1 shows the mounting of the model to the vibration fixture and the correlation of IM and ALSEP axes; vibration of the test model was in the direction of the ALSEP axes to the levels defined in Appendix 1. All screws on the model were assembled with "LOCTITE NUTLOCK" and tightened to the following torque leadings: -

SCREW SIZE

4-40

6-32

TIGHTENING TORQUE

7 Lb.-Ins.

9 Lb.-Ins.

TEST

The test started with vibration in the vertical axis (X_A), first in the sinusoidal mode followed by the random mode. No excessive vibration of components was noted during either mode and, as far as could be noted by eye, the dynamic envelope was small - in the order of 1/16 inch all round. On completion of this axis, the model was removed from the fixture and examined for any evidence of failure. None was noted, all parts appearing to have satisfactorily withstood vibration in this axis.

NOTE 1. - It is recommended that the vibration fixture be re-designed as a "box-type" fixture for testing of the prototype and future models.

Testing was then continued in the horizontal axes. At this point it was noted that the fixture (or rather, the individual mounting pillars) resonated at around 1000 Hz. This improved once the test model was secured to the pillars, but there were indications that resonance still occurred below 2000 Hz¹. The first horizontal axis to be run was across the width of the unit (Y_A). Once again, the sinusoidal mode was run, followed by random. In this axis also, the dynamic envelope looked good and was estimated to be similar to the vertical axis in magnitude. On completion of the random mode the model was removed from the fixture and examined for any evidence of failure. Externally, all was well, but upon shaking the model along its length there were audible indications that some part or parts were loose internally. At this point, the test was stopped and the model returned to Building 31 for disassembly and examinations.

POST-TEST EXAMINATION

Upon removal of the radiator plate and simulated electronics from the structure, it was found that the two "stacked" P/C board assemblies had become detached from the radiator plate. Dismantling the simulated electronics assembly revealed that the eight mounting pillars had failed where attached to the radiator plate (see Figure 2). Further examination showed that two of the eight mounting screws for the "stacked" P/C boards had broken close to the mounting pillars. Dismantling of the "stacked" P/C boards showed that seven of the 32 retaining washers securing the spacers (see Figure 3) had become loose (but not detached).

All other parts of the structure and electronics were sound and secure, and the dust-covers operated satisfactorily when released. It was also noted during disassembly that none of the screws (inserted as previously described) had "backed-off" or loosened.

During the next two days (20th and 21st May) the failures were investigated and corrected (see Appendix B) and on Thursday, 23rd, May, the unit was resubmitted to vibration test. Testing was only undertaken in the horizontal axes.

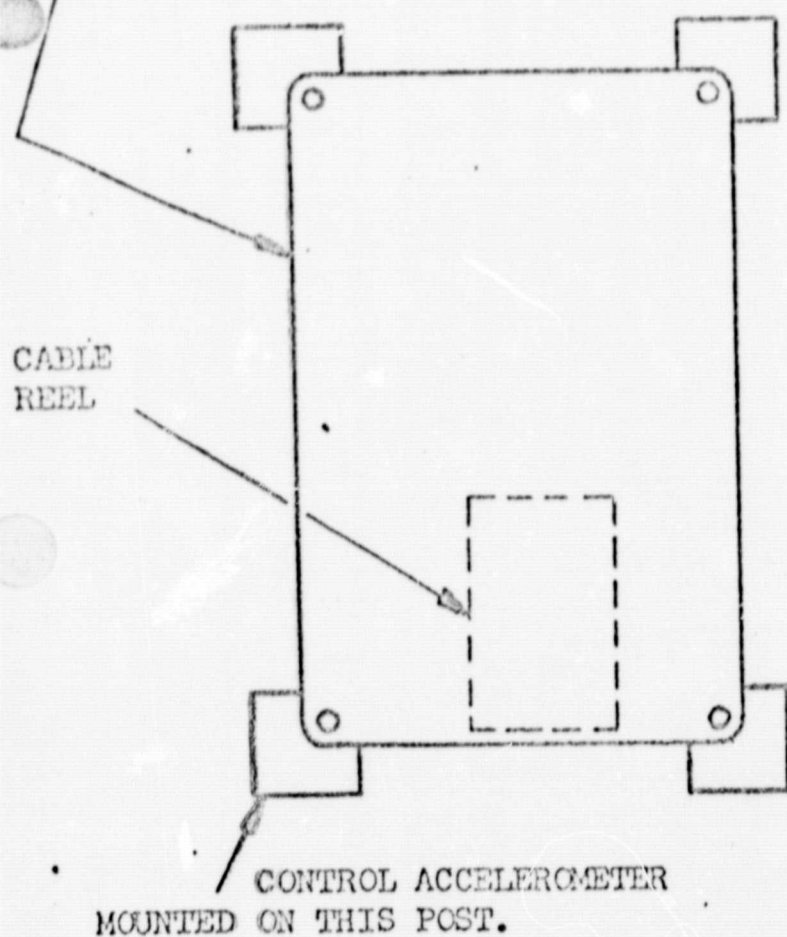
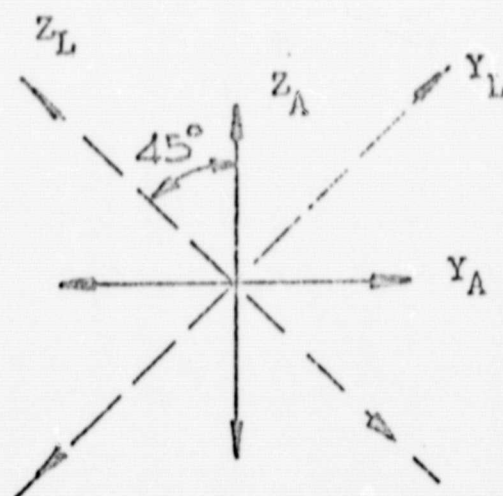
RE-TEST

The unit was re-tested first in the Y_A axis (in which it had previously failed) both in sinusoidal and random model. On completion, the unit was removed from the fixture and showed no evidence of failure. The test unit was replaced on the fixture and subjected to sinusoidal and random vibration in the Z_A axis. Once again, upon completion, the unit was examined for evidence of failure. None was to be seen (or heard). The test was then considered to be completed and the structural model returned to Building 31 to be disassembled and examined.

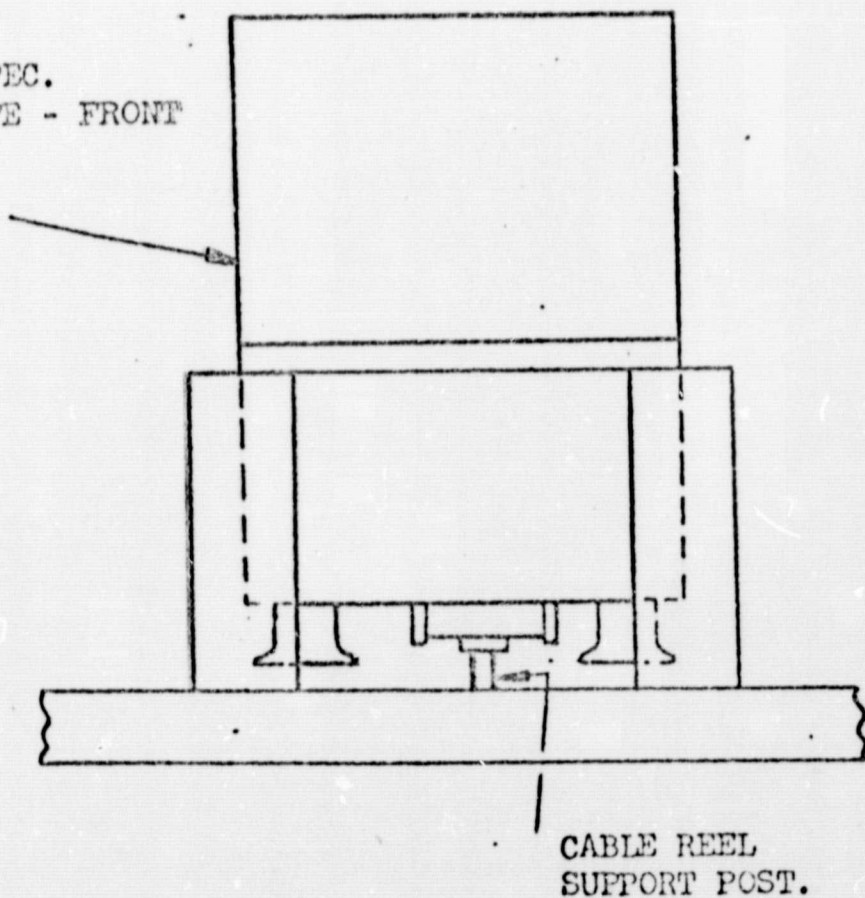
CONCLUSION

Upon disassembly, thorough examination of the model showed no evidence of failure of any of the parts. Hence, the structural model of the GALA is regarded as having satisfactorily completed its testing.

MASS SPEC. ENVELOPE - TOP VIEW



MASS SPEC. ENVELOPE - FRONT VIEW

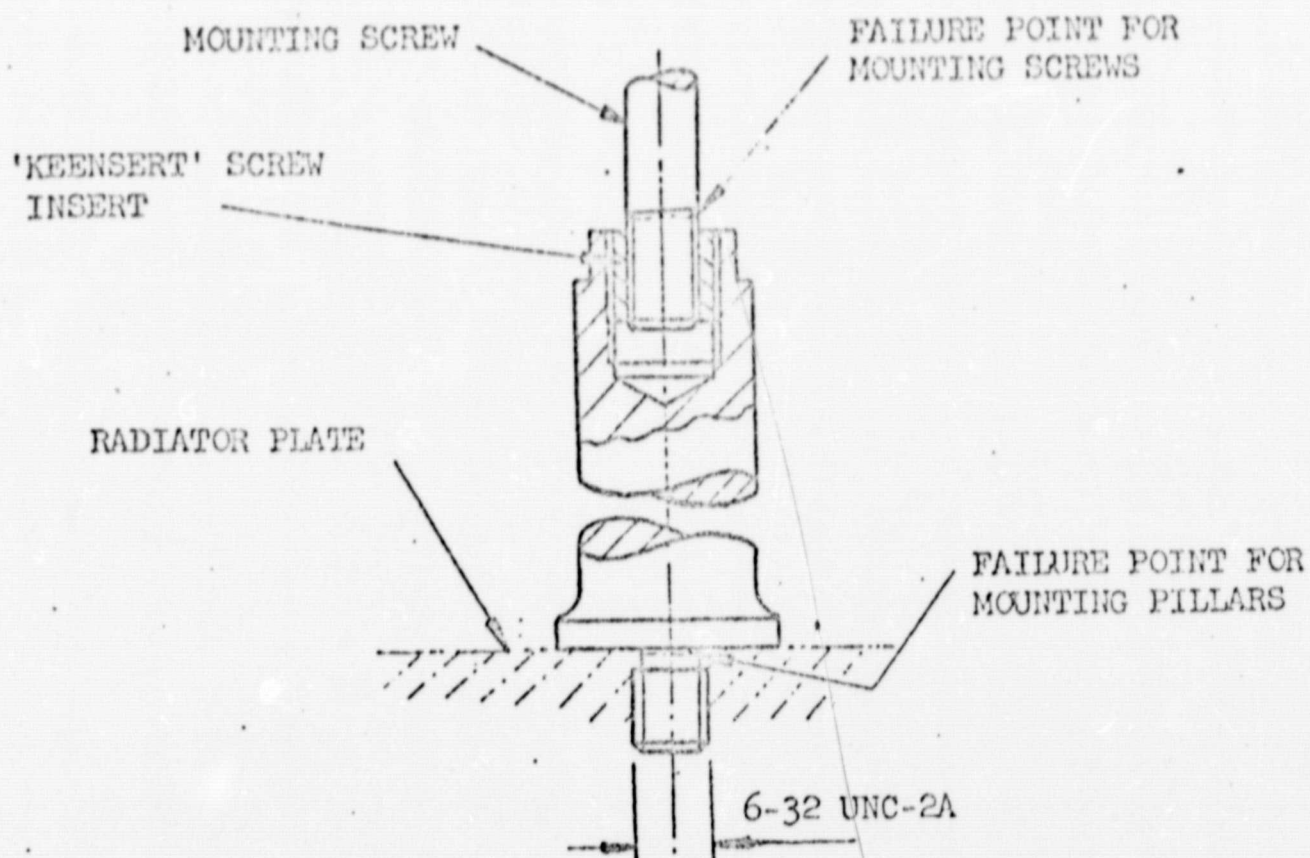


X_A, X_L

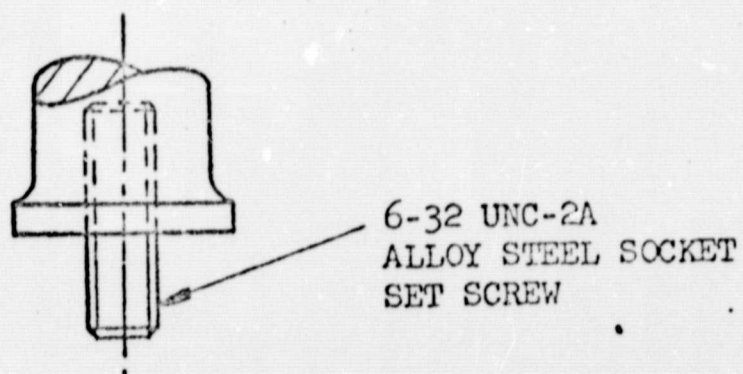
$X_A, Y_A, Z_A = \text{ALSEP AXES}$

$X_L, Y_L, Z_L = \text{LM AXES}$

FIG. 1 - TEST MODEL MOUNTING AND DEFINITION OF AXES



(a) FAILURE POINTS ON MOUNTING PILLARS



(b) MODIFICATION TO MOUNTING PILLAR

FIG. 2 - MOUNTING PILLAR FAILURE

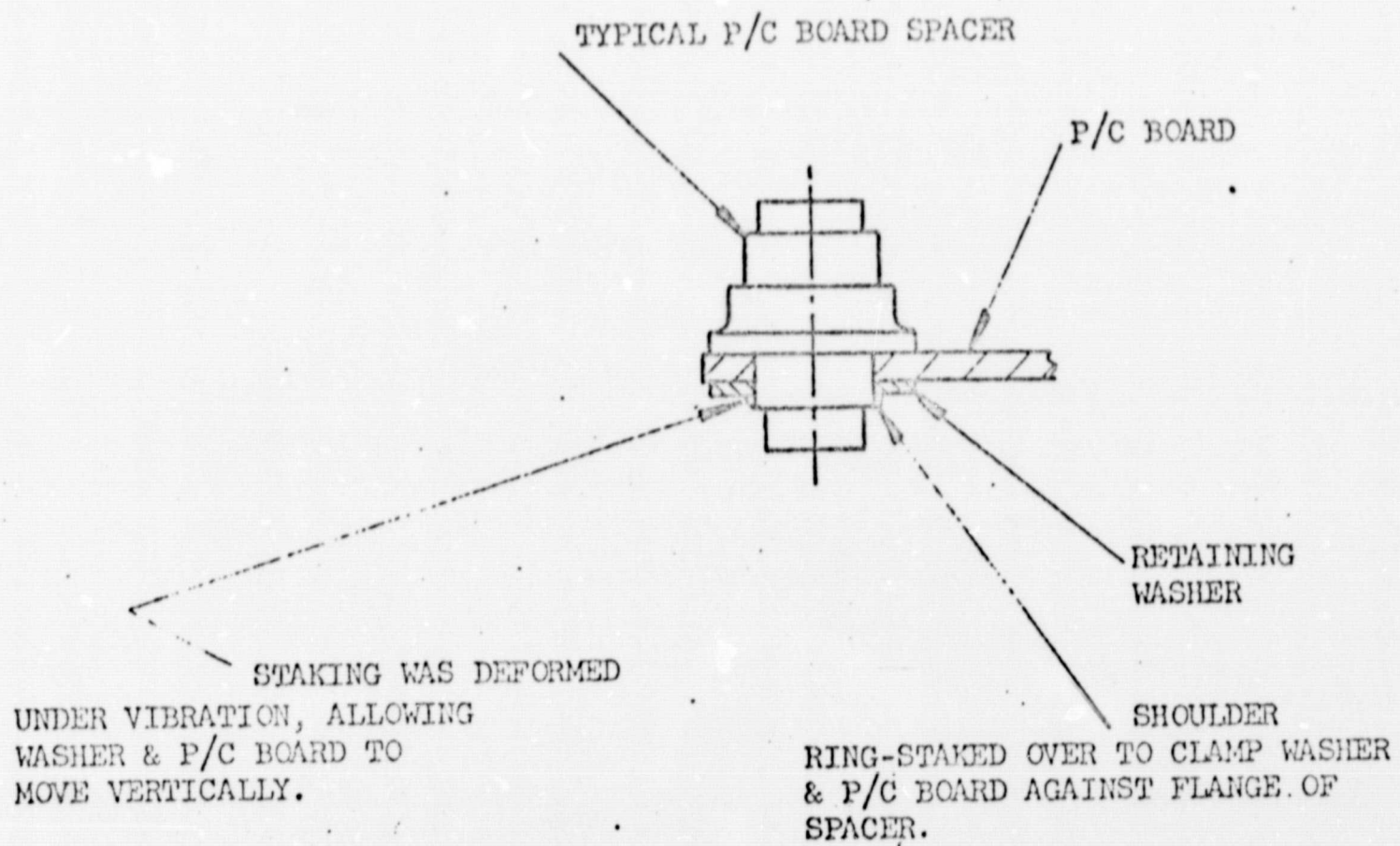


FIG. 3 - P/C BOARD SPACER

APPENDIX A
VIBRATION TEST LEVELS

SINUSOIDAL

<u>FREQUENCY</u>	<u>"g" LEVEL</u>	<u>DURATION</u>
5 - 20 Hz	0.370" D.A.	One sweep at 1 octave/min.
20 - 60 Hz	7.15 $\pm$ 1.0 (0 to peak)	
60 - 100 Hz	8.50 $\pm$ 1.0 (0 to peak)	Decrease frequency only.

RANDOM

<u>FREQUENCY</u>	<u>POWER SPECTRAL DENSITY</u> <u>(g²/Hz)</u>
23 - 60	12 dB/octave $\pm$ 1 dB increase
60 - 150	0.387
150 - 530	12 dB/octave $\pm$ 1 dB decrease
530 - 2000	0.00185

NOTE: - For details of test requirements see ERD-SM-1001, "Environmental Test Specification for the Mass Spectrometer".

APPENDIX B

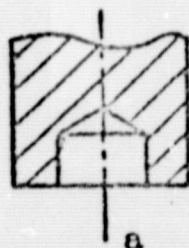
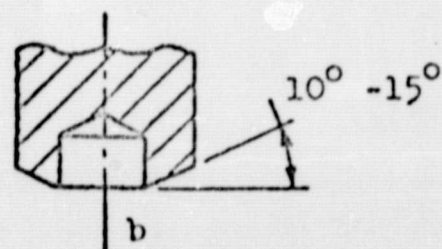
FAILURE INVESTIGATION AND CORRECTION

The failure of the mounting pillars at the point of attachment to the radiator plate was closely examined, and gave every indication of having failed due to stress concentration at the corner of the undercut closest to the shoulder of the pillar. Examination of unassembled pillars showed that the undercut at this shoulder had been made with a conventional "parting-off" tool and therefore had a very sharp internal corner. (The part drawing did not indicate that this was unacceptable.) Assuming that stress concentration was the primary cause of failure, a simple modification to eliminate the point of concentration was decided upon. As can be seen in Figure 2(b), the pillar was tapped to accept a set-screw, which was "epoxied" into the pillar to provide a permanent modification. This fix enabled the re-testing to be completed within 3 days of the original test, and was satisfactory on all counts.

It is suggested that the pillar design be modified to incorporate the set-screw, as it meets all the restraints placed on this particular attachment to the radiator plate. The additional strength of the set-screw provides a higher factor of safety in this area, to cover any contingency or modification to the electronics P/C boards.

Upon examination of the mounting screw failures (see Figure 2(a)) the opinion was formed that this occurred after the pillars had failed, and was due to the hammering of the stacked P/C boards and pillars against the side of the inner housing of the thermal bag. Therefore, no corrective action was taken and the subsequent re-testing was completed with no failure.

The loosening of the retaining washers (see Figure 3) was examined. None of the washers were actually free on the spacer, but two were capable of moving $3/64$ inch vertically and five others rotated upon the spacer, indicating that the ring-staking had backed off. The failure was attributed to inadequate staking. The tool used was a simple "home-made" punch (see (a) below) and the shoulder to be staked only allowed a limited amount (.012 inch) of material to be deformed. The loose washers were re-staked, using the same tool as before and successfully completed test. However, it is recommended that the staking tool be modified (see (b) below) to deform more material over the washer and clinch it tighter; also the detail design of the spacers should be investigated to determine whether a wider shoulder for staking could be provided.



APPENDIX D
RESULTS
OF THE
THERMAL-VACUUM TEST
ON THE
MASS SPECTROMETER EXPERIMENT
(GALA)

RESULTS
OF THE
THERMAL-VACUUM TEST
ON THE
MASS SPECTROMETER EXPERIMENT
(GALA)

Prepared by: _____

Approved by: _____

Lang B. York

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER

April, 1970

THERMAL-VACUUM TEST RESULTS FOR THE MASS SPECTROMETER (GALA)

The thermal-vacuum test model of the Gas Analyzer Lunar Application (GALA) mass spectrometer was tested at the facility of the Space Environment Test Division, Space Environments Effects Section in Building 33 at the Manned Spacecraft Center. The test began on June 15, 1969 and was completed on June 20, 1969.

The purpose of the test of the thermal-vacuum test model was to provide data in evaluating the overall thermal design of the mass spectrometer electronics package and to show that the experiment was capable of surviving the specified environmental requirements for lunar surface operation.

The thermal-vacuum test model consisted of all mass spectrometer structural components together with simulated electronics (Figures 1, 2, 3, 4). The electronics were simulated using resistors epoxied to printed circuit boards to duplicate the heat output in the actual model electronics (see Table I for power output of each printed circuit board). Thermal control heaters were installed on the radiator plate to simulate survival conditions. The power supplies for the simulated electronics and thermal control heaters were located external to the test chamber.

The thermal-vacuum test model was coated on all exposed surfaces with Goddard coating formulation MS-74. MS-74 has a solar absorptance of 0.22 and an IR emittance of 0.88. The radiator plate was covered with solar reflecting mirrors having a solar absorptance of $\alpha_s = 0.050 \pm 0.005$ and a total hemispherical emittance of $e = 0.80 \pm 0.02$.

NASA 69-37902

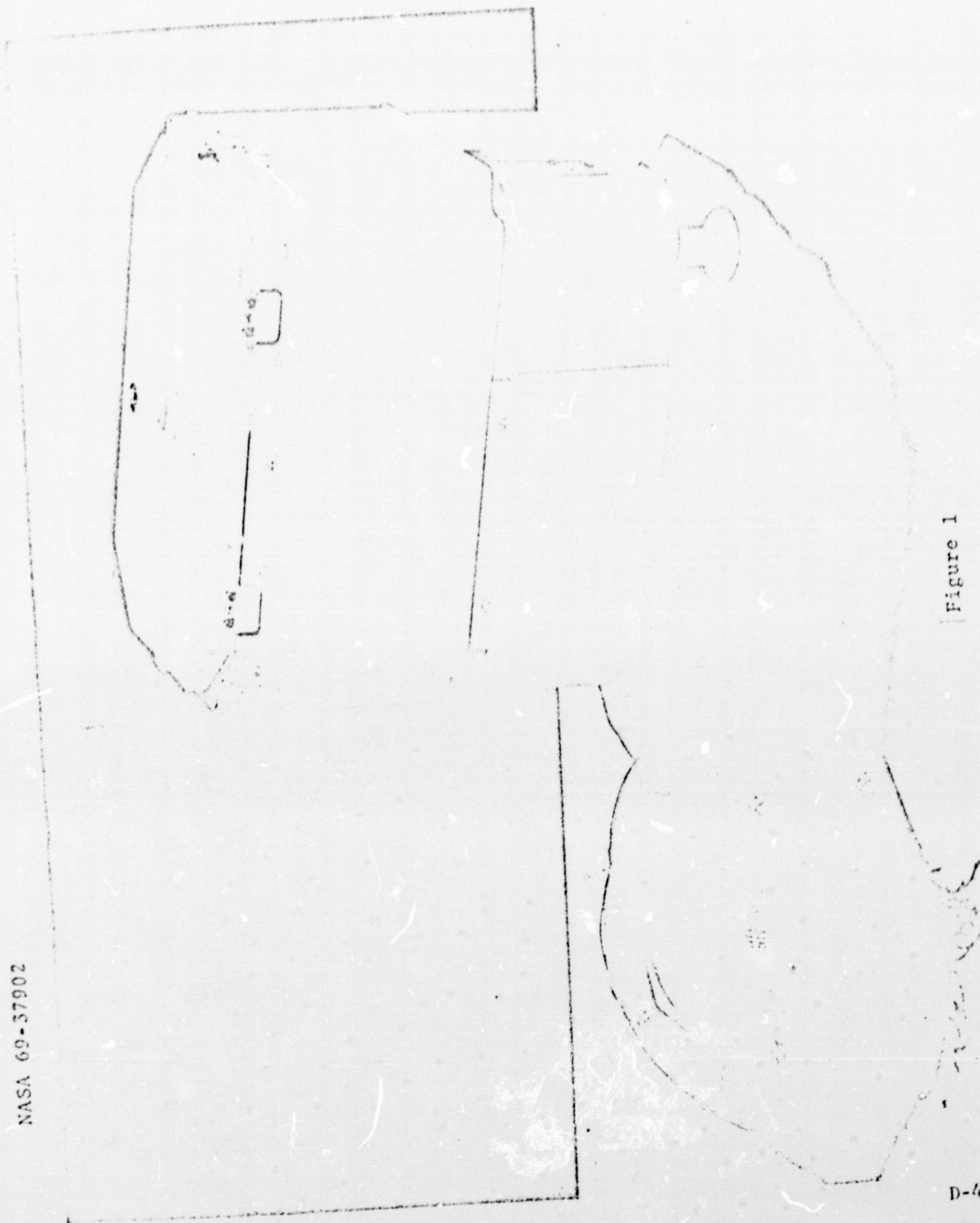


Figure 1

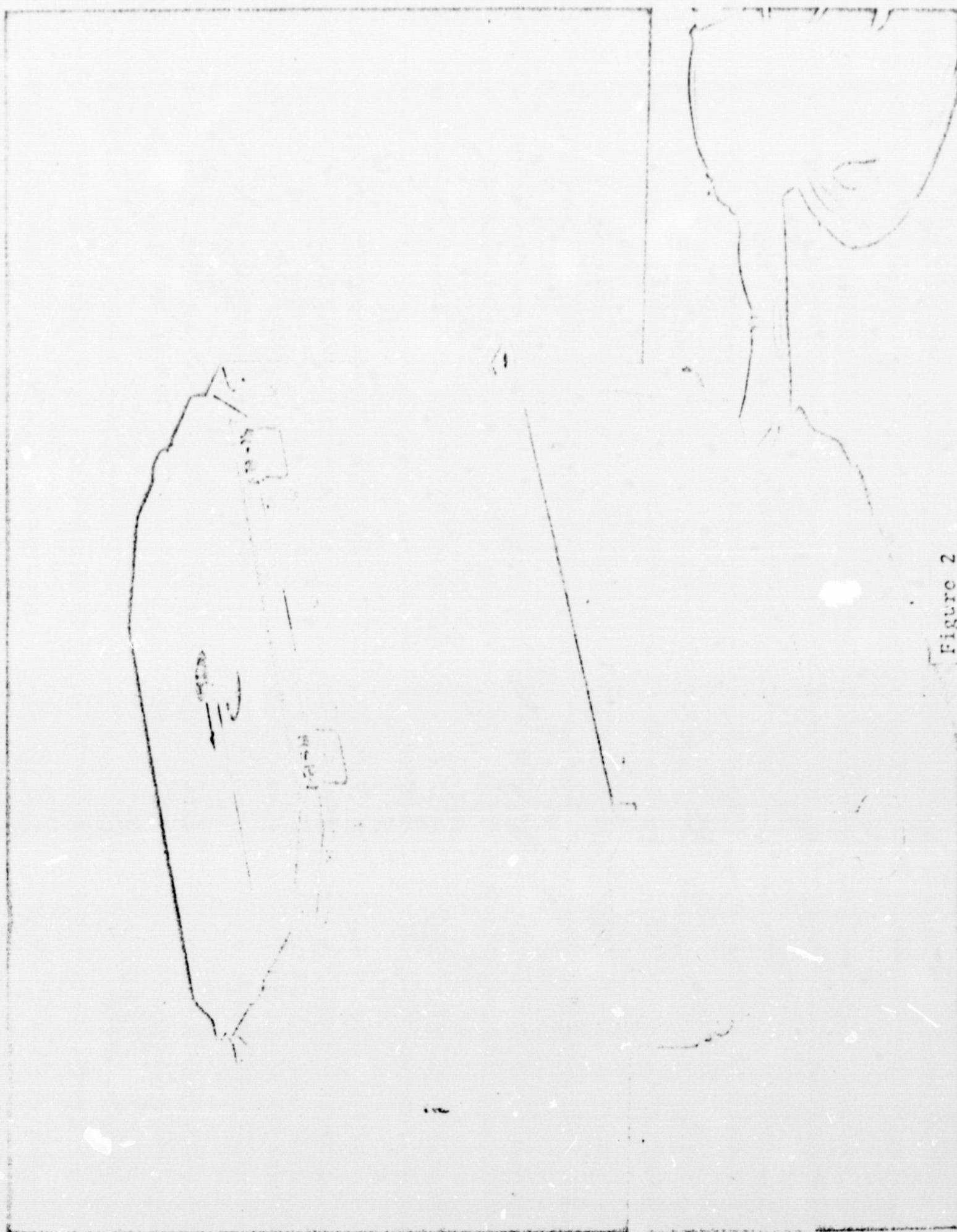


Figure 2

NASA 69-57905

NASA 69-37897



Figure 3



Figure 4

NASA 69-37894

Table 1
PRINTED CIRCUIT BOARD POWER OUTPUT

Printed Circuit Board <u>(No.)</u>	<u>I</u> (mA)	<u>Power</u> (mW)
1 Switching P.R.	130.	1,560.0
2 L.V.	150.	1,800.0
3 H.V.	140.	1,680.0
4 Emission Control	168.	2,020.0
5 Squib-Fire Board	.54	6.5
6	56.1	674.0
7	55.0	660.0
8	54.8	660.0
9	55.75	670.0
10	31.5	378.0
11	23.5	282.0
12	34.9	<u>419.0</u>
Total		10,809.5 mW
		<u>10.8095 Watts</u>

Fifty-four (54) thermocouples were attached to the test model at the locations indicated in sections 2.1 through 2.6 as shown in Appendix A. During the test, the temperature of each thermocouple was recorded at least once each fifteen minutes on a computer print-out.

The test model was mounted on a 30- x 34-inch sheet of aluminum painted black with 3M formulation 401-10C, simulating the lunar plane. While mechanical attachment of the thermal model to the lunar plane was necessary, it was also highly desirable to keep thermal contact between the two to a minimum. This was accomplished by use of four stainless steel bolts and teflon spacers.

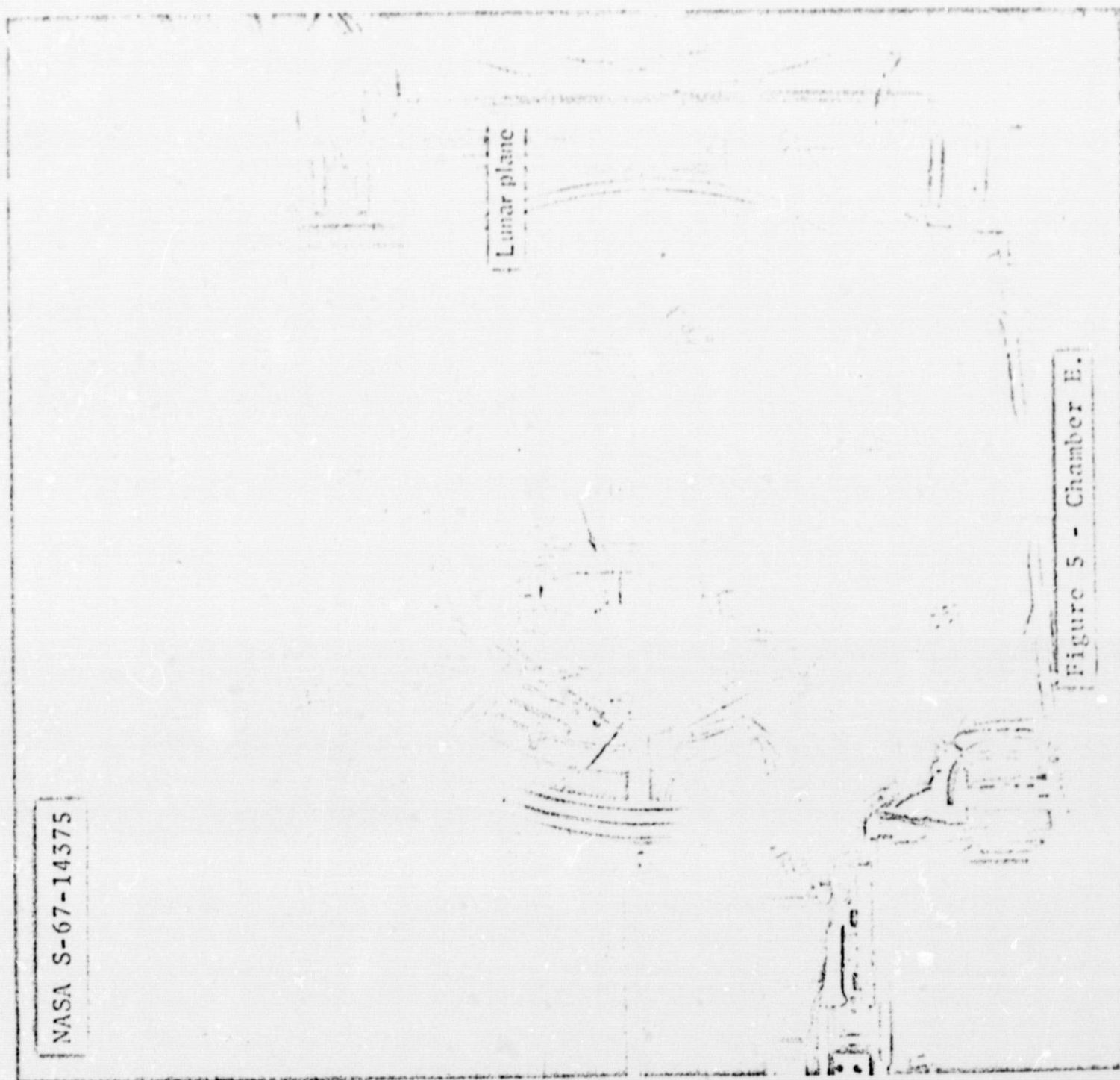
Quartz lamps were mounted on the back of the lunar plane for lunar plane temperature control. The lunar plane was mounted in the chamber, with a vertical axis of rotation through the 30-inch dimension. The center of the lunar plane and its axis of rotation were in the center of the solar beam. The rotation of the lunar plane was controlled from outside the chamber. The back of the lunar plane can be seen in the chamber in Figure 5.

The pressure for all tests was in the range of 10^{-8} torr.

The chamber liner was painted black and cooled with liquid nitrogen during all the tests, simulating cold space.

A carbon-arc lamp (Genarco model ME-6) was used to simulate the solar beam. The energy flux at the lunar plane was monitored by use of a radiometer. During the test the lunar plane temperature was controlled to simulate the temperature of the lunar surface, consistent with the solar phase angles. This was accomplished by monitoring the lunar plane temperature with several thermocouples and varying the intensity of quartz lamps as required.

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.



The thermal-vacuum test consisted of control and operational adjustments of simulator and instrument, and functional instrument tests simulating four phases or conditions of operations. A description of the tests that were conducted is contained in the following paragraphs.

Phase A:

Simulated operation of instrument during lunar night with only heaters ON. The test model was mounted to the lunar plane as shown in Figure 6. The model was mounted with its two axis aligned with the solar reflecting mirrors perpendicular to the solar beam (see Figure 7 for orientation axes of instrument).

Phase B:

Simulated operation of instrument during lunar night utilizing the electronics as the only source of heat.

Phase C:

Simulated operation of instrument during lunar noon with simulated electronics operational.

Phase D:

Simulated operation of instrument during lunar morning (sun angle at approximately 45°) with simulated electronics operational.

The preliminary control and operational adjustments of the simulator and instruments are briefly outlined as follows:

The instrument was placed in the environmental test chamber and at 0 hours, heater No. 1 of the instrument was turned ON (See Figure 8). At approximately 5 3/4 hours, liquid nitrogen

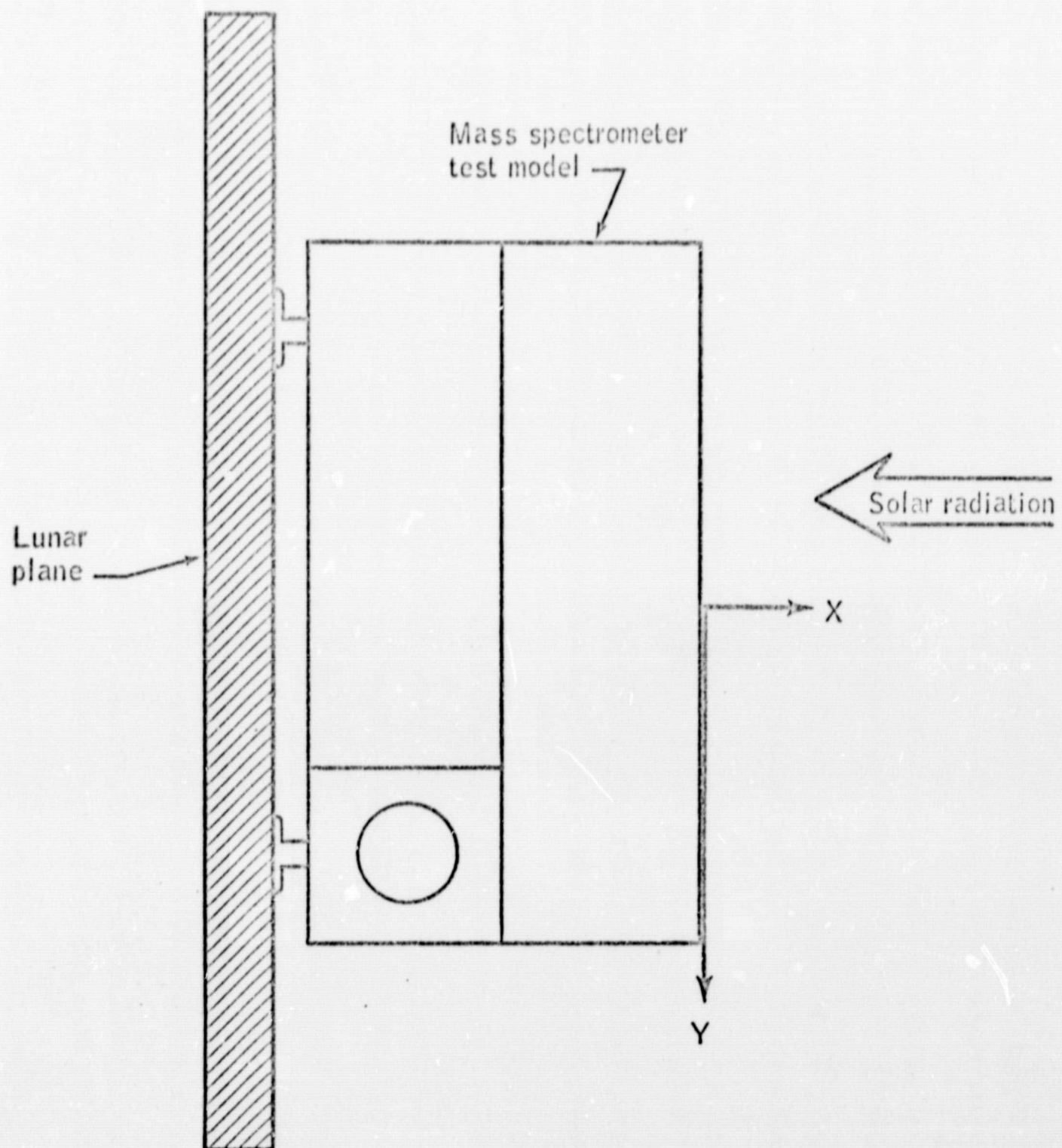


FIGURE 6. THERMAL TESTS SETUP

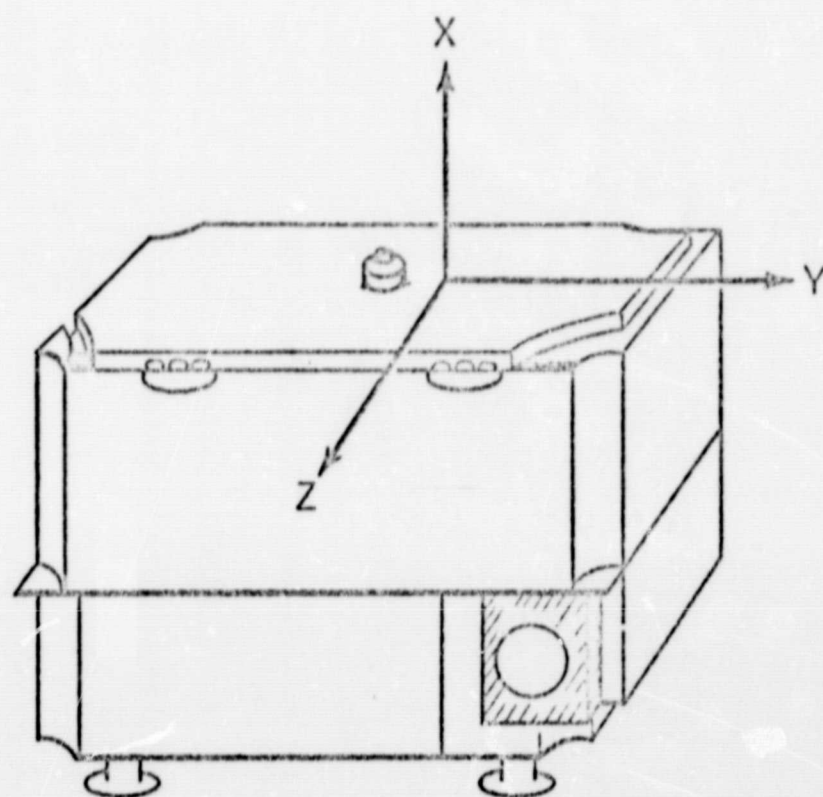
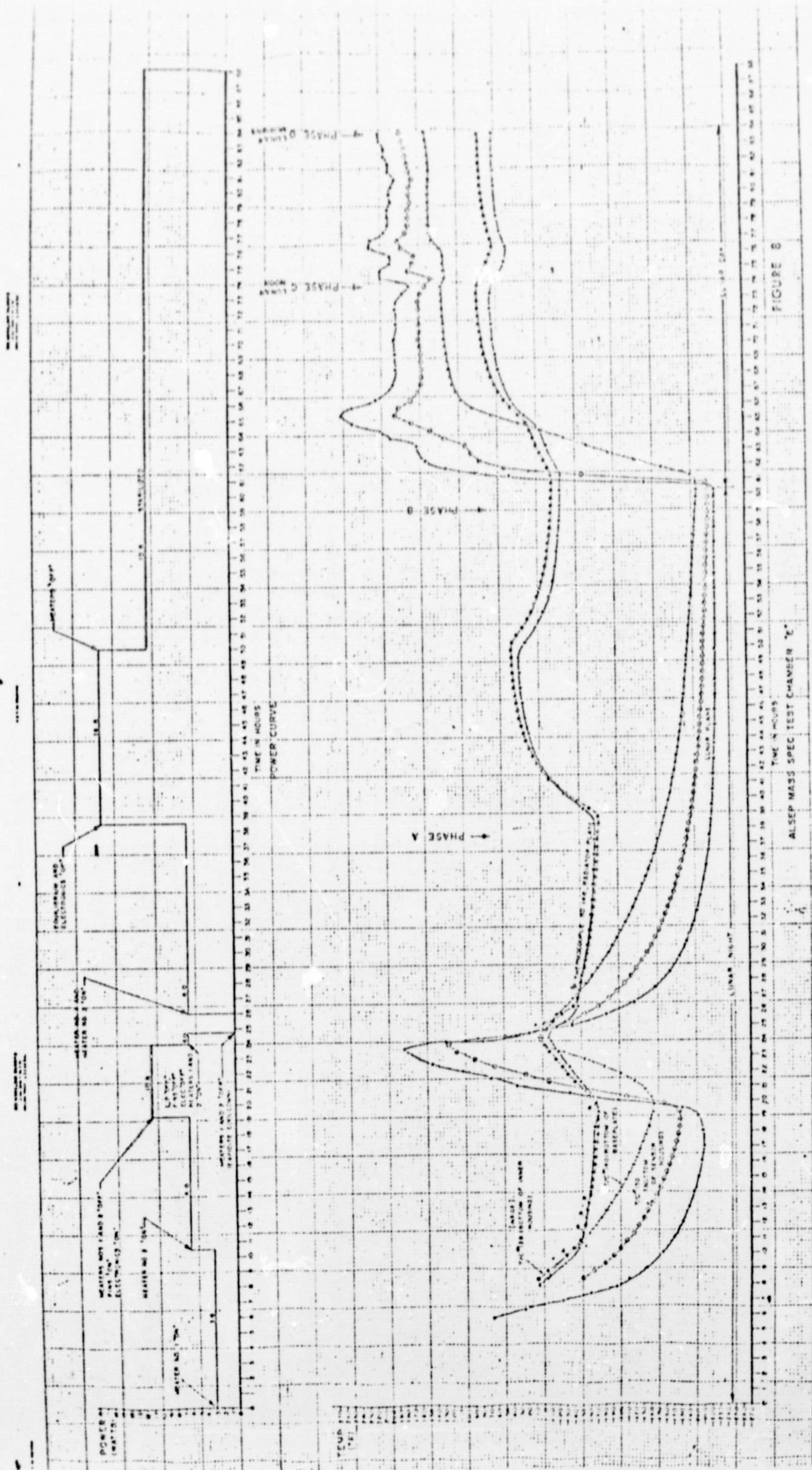


FIGURE 7. AXES OF ORIENTATION



was added to the chamber and the lunar plane began to cool down to simulate the lunar night. At 10 1/2 hours, instrument heater No. 2 was turned ON to stabilize and test the instrument in the cold environment. Just after 19 hours, the instrument heaters were turned OFF, and the instrument electronics turned ON to test the thermal stability of the heat flow of the instrument with just electronics' heat during the lunar night. Through an error in judgement, the lunar plane heaters were prematurely turned ON. This interrupted the tests for a period of 8 hours. The testing, in effect, began at 24 3/4 hours.

Phase A (Lunar night, instrument heater power only):

Cooling of the lunar plane was commenced and at 38 1/2 hours the lunar plane temperature stabilized at -220°F simulating lunar night. During the cooling period, as the lunar plane temperature went from 0°F to -220°F, the radiator plate and the electronics varied only from -45°F to -70°F indicating that a heater power of 6 watts would stabilize the radiator plate and electronics temperatures within this limit.

The temperatures of various points within the instrument are summarized in Table 2.

Phase B (Lunar night, electronics power only):

During this phase of lunar-night testing the lunar plane was maintained at a temperature from -220°F to -230°F. While at this temperature, the test plan called for a test of the thermal-control properties of the instrument using full operation of the electronics. This test was carried out over the time period 38 1/2 hours to 60 1/2 hours. At the outset of the test with the radiator plate at -70°F from the prior test, the electronics were turned ON providing 10.8 watts of heating

Table 2

SUMMARY TEMPERATURE PROFILE

Note: Applied power for tests is as follows:

A - Heaters #1 & #2 = 6.0 watts
 B - Electronics = 10.8 watts
 C - Electronics = 10.8 watts
 D - Electronics = 10.8 watts

THERMOCOUPLE/LOCATION	LUNAR NIGHT		LUNAR NOON	LUNAR MORNING
	Phase A (@ 38- hrs) (Temp °F)	Phase B (@ 60- hrs) (Temp °F)	Phase C (@ 73- hrs) (Temp °F)	Phase D (@ 84 hrs) (Temp °F)
<u>FIGURE 8</u>				
Lunar Plane	-220	-230	+185	+200
146, Radiator Plate	- 70	- 30	+ 55	+ 55
140, Bottom of Base Plate	-160	-210	+120	+140
130, Bottom of Sensor Housing	-195	-220	+140	+175
138, Inside Bottom of Inner Housing	- 75	- 20	+ 75	+ 70
<u>FIGURE 9</u>				
174, Edge of Radiator Plate	- 75	- 35	+ 55	+ 55
137, Inside Mounting Ring	- 75	- 35	+ 55	+ 55
127, Outside Mounting Ring	-120	- 90	+ 75	+ 80
129, Outer Housing	-130	-110	+ 75	+ 80
<u>FIGURE 10</u>				
147, Collars	- 70	- 20	+ 65	+ 65
150, Pillars	- 70	- 30	+ 60	+ 55
<u>FIGURE 11</u>				
PC Boards				
156, 158, 172, 170	- 70	- 10	+ 80	+ 75
157, 173, 169	- 70	- 15	+ 70	+ 70
<u>FIGURE 12</u>				
161, 153, 160, 159	- 70	+ 5	+ 85	+ 80
152, 164, 167, 168	- 70	- 10	+ 75	+ 70
<u>FIGURE 13</u>				
155, 162, 154, 151	- 70	+ 5	+ 85	+ 80
166, 163	- 70	- 15	+ 70	+ 65

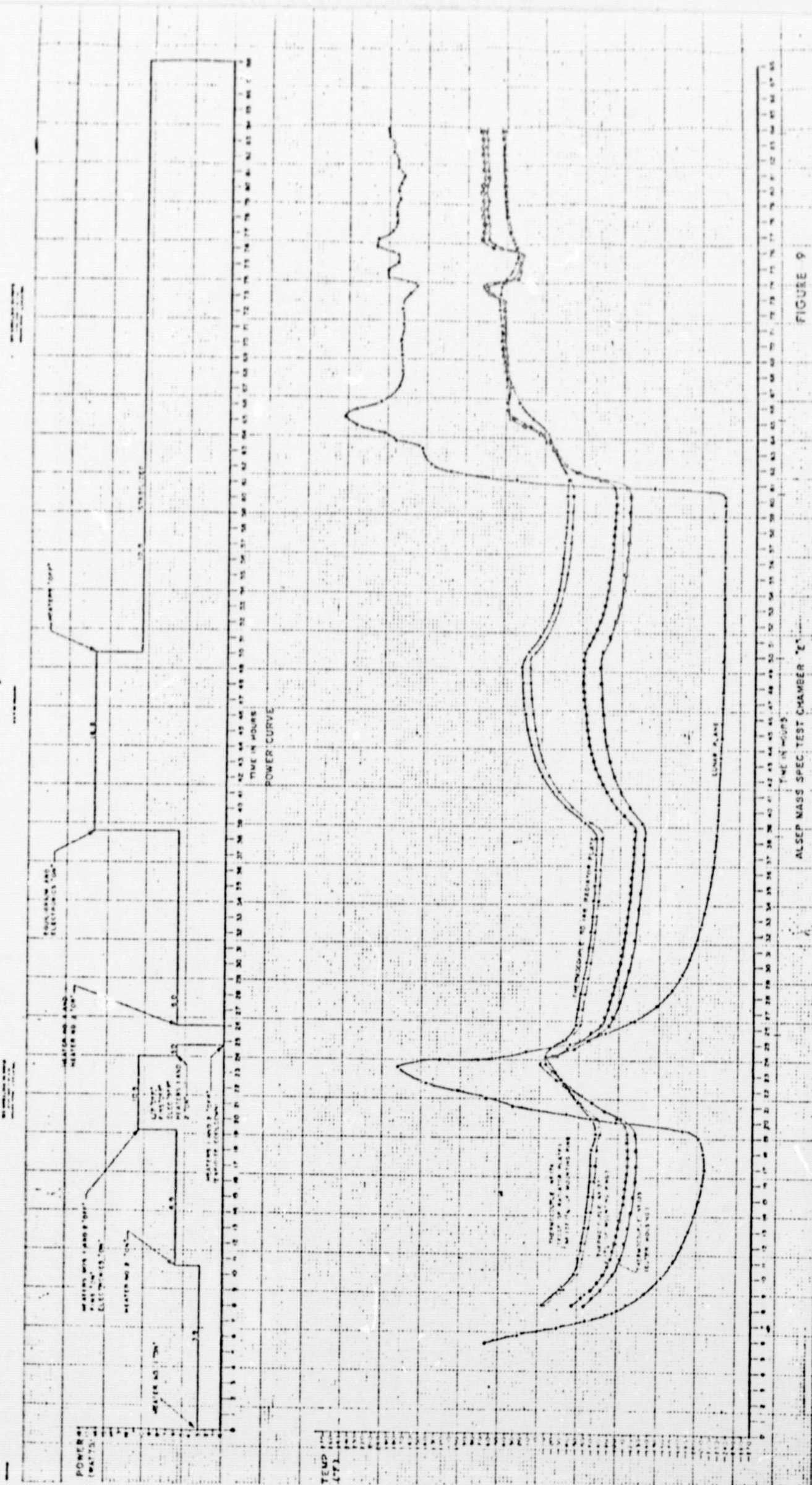
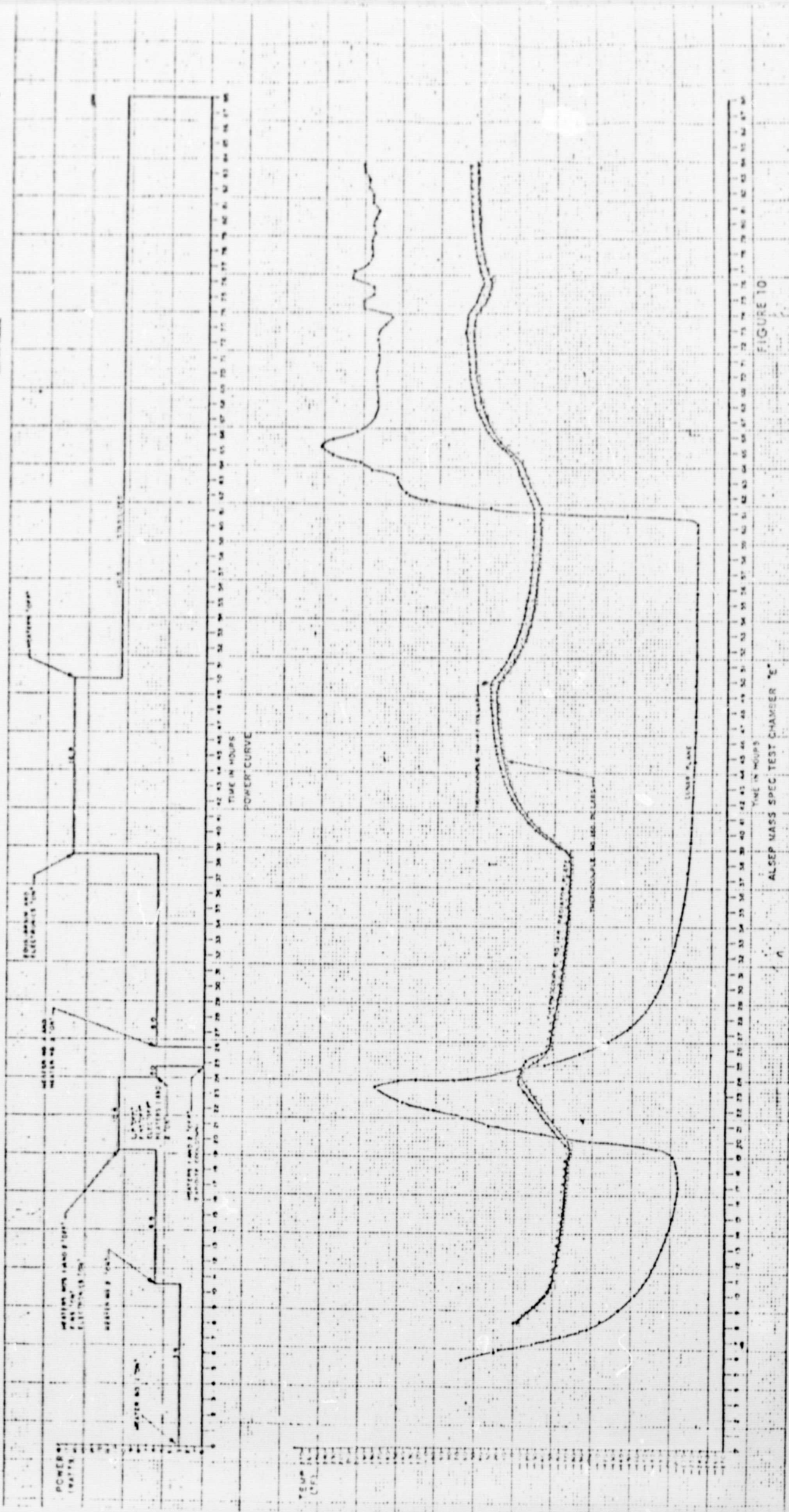


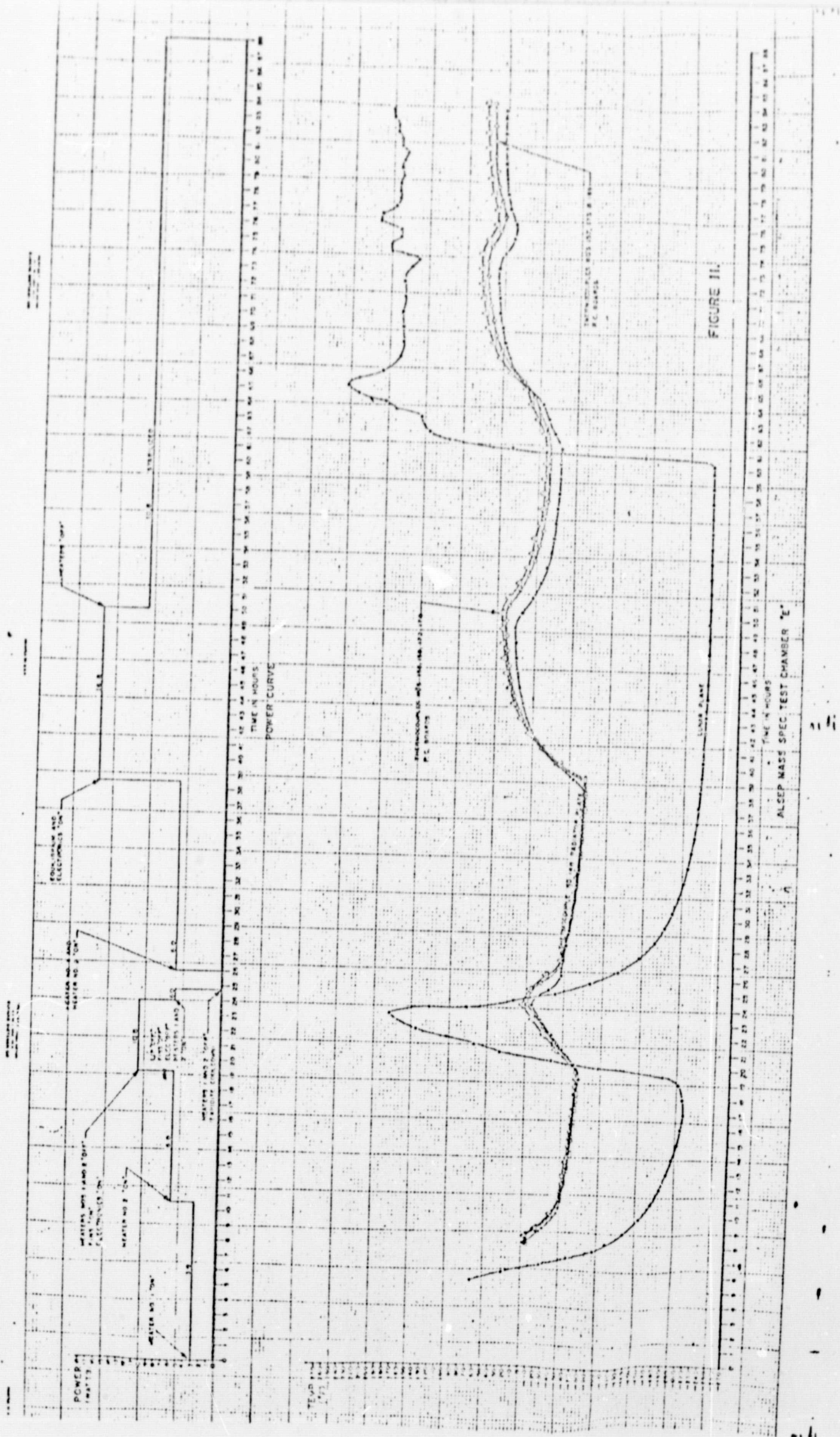
FIGURE 9

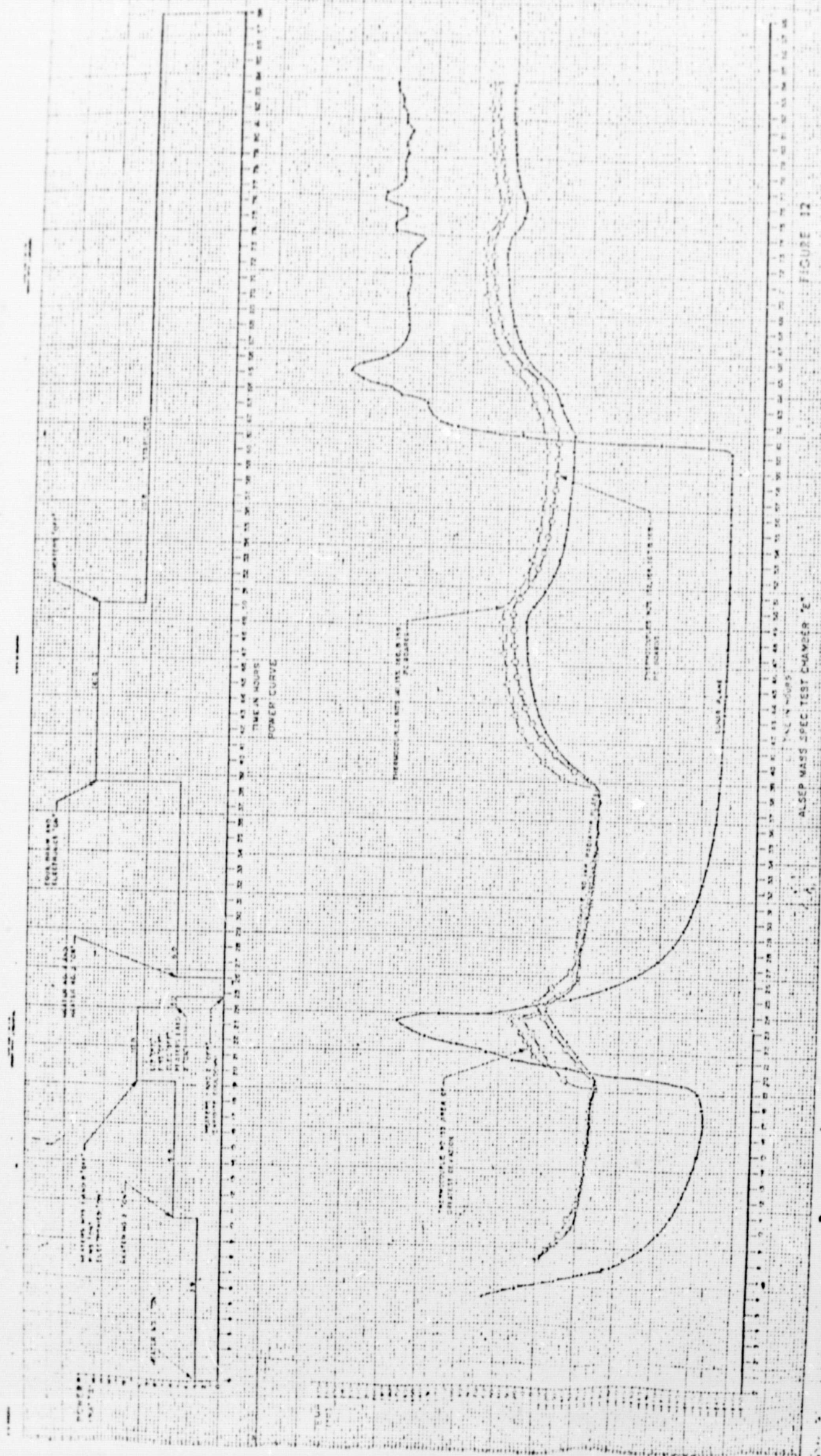
ALSEP MASS SPEC TEST CHAMBER "2"

ALSEP MASS SPEC TEST CHAMBER "E"

FIGURE 10







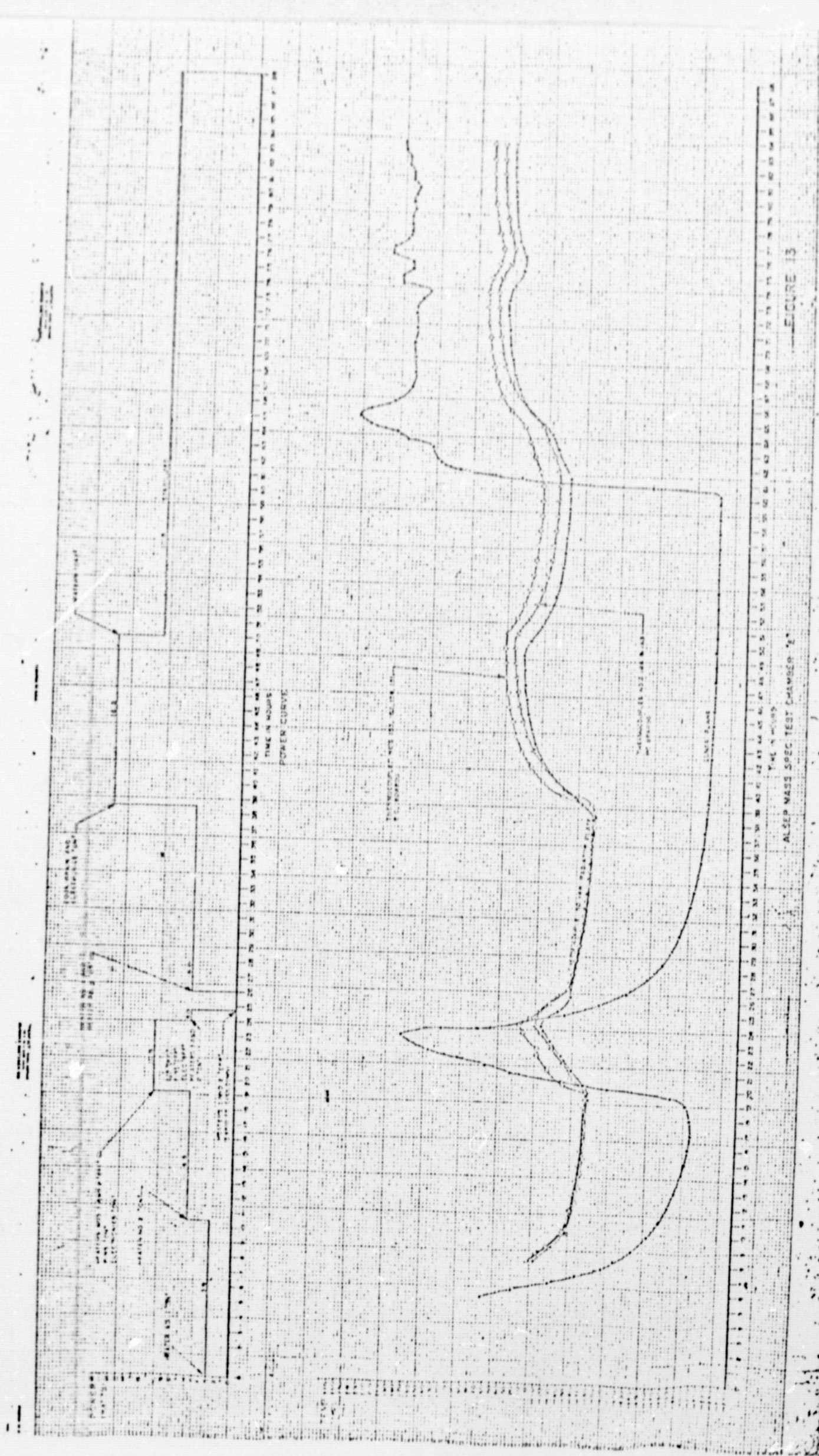


FIGURE 13

power giving 16.8 watts of total heating power as the heaters were still ON. For this test, only the electronics were to be ON; the heaters were to be OFF. During the time the total power was ON (for 11 1/2 hours), the radiator-plate temperature rose to +25°F, which was not detrimental to the test of the instrument; however, this did not represent the desired test of the instrument during this phase of the lunar night.

At 50 hours, the heaters were turned OFF and the simulation of normal operation of the instrument with only the electronics ON during the lunar night was commenced. After environmental stability had been attained (at 60 1/2 hours), the radiator plate stabilized at -30°F and the printed circuit boards stabilized in the range from +5°F to -15°F at the time the lunar plane temperature was at -230°F. (See Table 2)

Phase C (Lunar noon, electronics power only):

The Phase C test was designed to test the thermal-control properties of the instrument packaging with the electronics operational (no heaters ON) during a lunar noon. The lunar-noon test took place during the period 60 1/4 hours and 73 3/4 hours. At 60 1/2 hours the heaters on the lunar plane and the solar simulator (high-intensity quartz lamp) were turned ON. The temperature of the lunar plane rose rapidly and in approximately five hours peaked at +225°F. Shortly thereafter, the lunar plane stabilized at approximately +185°F. A desired temperature of +250°F for the lunar plane was not obtainable during the lunar day operation due to chamber difficulties.

During this time the temperatures of the electronics (printed circuit boards) stabilized in the range from +70°F to +85°F. (See Table 2)

Phase D (Lunar morning, electronics power only):

The Phase D test was designed to test the thermal-control properties of the instrument packaging with the electronics operational (no heaters ON) during a lunar morning. The lunar plane in the environmental chamber was rotated 45° such that the incident angle of the solar beam on the instrument would represent the sun angle on the instrument with respect to the lunar surface. The lunar plane and the instrument reached thermal stability at 84 hours at which time the thermal data for a lunar morning was summarized.

While the lunar plane temperature was increased from $+185^\circ\text{F}$ to approximately $+200^\circ\text{F}$, the radiator plate remained stable at $+55^\circ\text{F}$. The electronics (printed circuit boards), however, during lunar morning showed a slightly cooler temperature of 5°F less over the range of $+65^\circ\text{F}$ to $+80^\circ\text{F}$ than lunar noon temperatures ($+70^\circ\text{F}$ to $+85^\circ\text{F}$). (See Table 2)

SUMMARY

Results of these tests indicate this packaging design will maintain the desired thermal/vacuum control of the mass spectrometer in a lunar environment.

APPENDIX A

THERMOCOUPLE LOCATIONS
FOR
THERMAL TEST UNIT

Appendix A
THERMOCOUPLE LOCATIONS
FOR
THERMAL TEST UNIT

1.0 OBJECTIVE

This appendix provides all thermocouple positions that are located on the thermal test unit of the Mass Spectrometer.

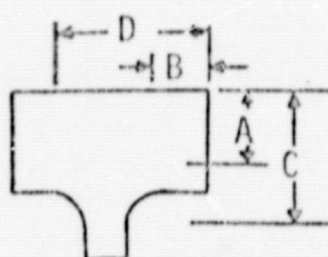
2.0 LOCATIONS

The thermocouples positions are located on the printed circuit boards, outer and inner housings, base plate, radiator plate and analyzer in the following sequence:

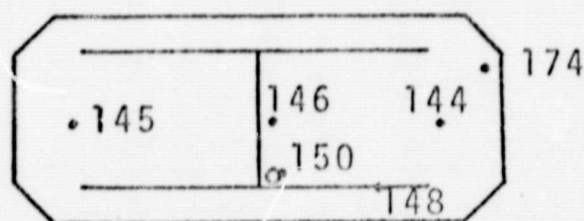
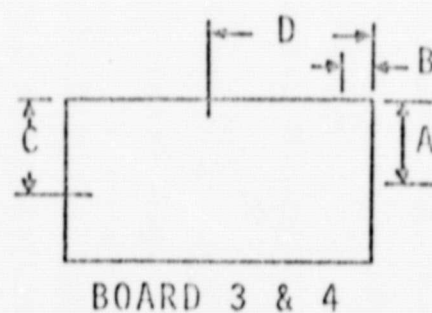
2.1 Printed Circuit Boards

P.C.B. No.	Thermocouple No.	Dimensions A	Dimensions B	Thermocouple No.	Dimensions C	Dimensions D
12	157	4.3	.65	156	1.6	2.3
11	173	3.4	.2	158	3.3	2.3
10	Open	2.4	.125	172	3.12	2.2
9	169	3.5	.2	170	3.4	2.2
8	166	3.9	.2	168	3.55	2.17
7	Lost	4.2	.2	167	2.7	2.15
6	163	4.0	.2	164	1.75	2.05
5	-	-	-	152	3.175	1.9
4	151	1.45	.2	161	2.7	2.95
3	154	1.45	4.75	153	1.15	2.65
2	162	1.3	4.2	160	2.15	2.10
1	155	.95	.7	159	1.3	2.0

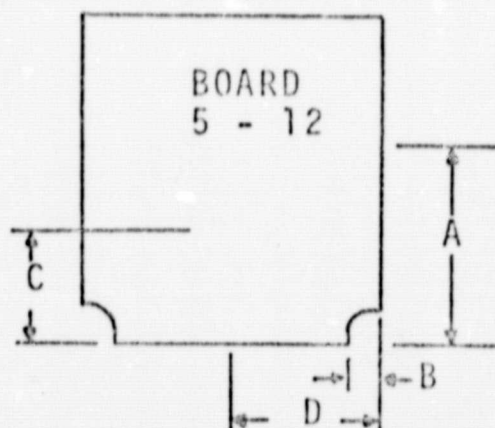
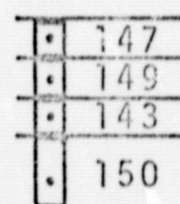
5 7
 6 8
 11 9
 12 10



BOARD 1 & 2



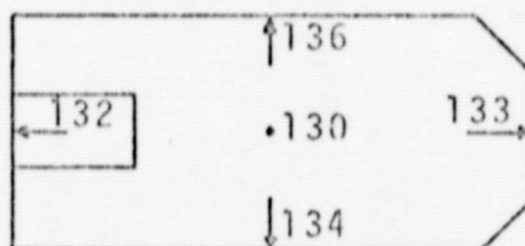
BOARD 3 & 4



2.2 Radiator Plate

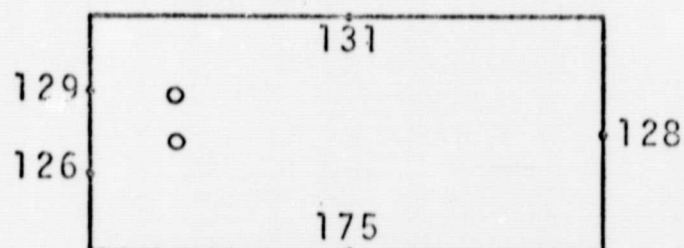
- 146 Center of radiator plate
- 150 Mounting post
- 148 Bottom rib of radiator plate
- 144 Edge of radiator plate, under switching pre-regulator
- 145 Radiator plate, under low voltage
- 174 Far edge of radiator plate - next to inner housing
- 147 Bottom - spacer-on mounting post
- 149 Middle - spacer-on mounting post
- 143 Top - spacer-on mounting post (next to top of radiator plate)

2.3 Sensor Housing



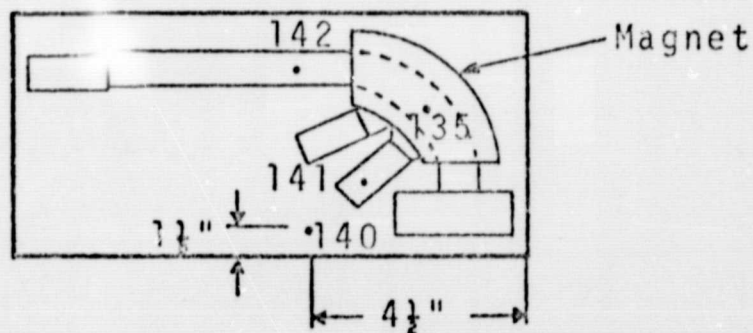
- 130 Center of bottom of sensor housing
- 136 1/2 way-up on sensor housing
- 133 1/2 way-up on sensor housing
- 134 1/2 way-up on sensor housing
- 132 1/2 way-up on sensor housing

2.4 Outer Housing



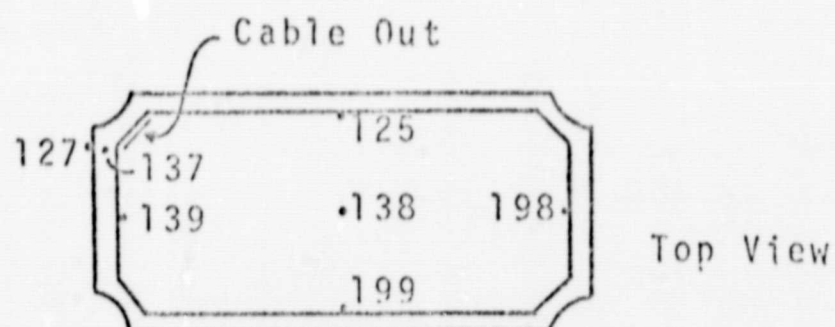
- 129 Top edge
- 126 Middle of housing - end
- 175 Middle of housing - side
- 131 Middle of housing - side
- 128 Middle of housing - end

2.5 Sensor



- 142 On sensor
- 141 On electron multiplier
- 140 On base plate
- 135 On magnet

2.6 Inner Housing



- 138 Center of bottom - inner housing
- 137 Edge of ring - inside
- 127 Edge of ring - outside
- 125 Center of side
- 139 Center of edge
- 198 Center of edge
- 199 Center of side

3.0 POWER REQUIREMENTS

Each printed circuit board for the thermal unit is supplied with heater resistors to simulate the true electronics power. The following table lists each board.

P.C.B. No.	I (mA)	Power (mW)
12 (5)*	34.90	419.0
11 (8)	23.5	282.0
10 (7)	31.5	378.0
9 (3)	55.75	670.0
8 (2)	54.8	660.0
7 (1)	55.0	660.0
6 (4)	56.1	674.0
5 (6)	0.54	6.5 (squib fire board)
4 Emission Control	168	2,020.0
3 H.V.	140	1,680.0
2 L.V.	150	1,800.0
1 Switching P.R.	130	1,560.0
		<u>10,809.5</u> or <u>10.8095 Watts</u>

Note: All P.C. boards are coated with Eccocoat 582.

* Numbers in () are as listed on the outline drawing of the electronics.

APPENDIX E

FAMILIARIZATION MANUAL

for

GALA

(Gas Analyzer for Lunar Atmosphere)

(Preliminary)

Southwest Center for Advanced Studies

September 22, 1969

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1.0

EXPERIMENT DESCRIPTION

The Gas Analyzer for Lunar Atmosphere (GALA) is a small magnetic sector-field mass spectrometer with three collectors, one to measure the mass range from 1 to 4 amu, another to measure the 12 to 45 amu range, and the third to measure the range from 40 to 160 amu. It contains a Nier-type thermionic electron bombardment ion source, and a digitally controlled high voltage sweep circuit, the output wave form of which is a series of voltage steps approximating an exponential decay. The data system is also digital. Ions emerging from each of the collectors are counted, the counting periods being synchronized to the digital steps of the high voltage sweep circuit. The instrument operates by gases entering the ion source chamber which is tightly coupled to the ambient atmosphere. Ions formed in this source chamber at a high positive voltage, are accelerated through a pair of exit slits and collimated into a beam which enters the magnetic analyzer at ground potential. The beam traverses uniform magnetic field which separates the ions into three different trajectories in the mass ratio 1:12:40. Ions meeting the focus conditions in each case pass through a collector slit and are counted by three independent counter systems. The spectrum is scanned by varying the ion accelerating voltage stepwise as is explained above.

The advantage of a triple collector analyzer can be seen as follows: The mass range scanned is an inverse linear function of ion accelerating voltage. In order to obtain a wide mass range (1 to 150 amu), an excessive range of voltage would have to be swept. This is undesirable since the resolution of the instrument is seriously degraded at voltages below 250v. By splitting the mass range into three parts roughly the cube root of the above voltage range is required. An accelerating voltage range of 1200 to 320 volts will permit the mass range 1 to 4 amu to be scanned on one collector, 12 to 45 amu to be scanned to the second collector, and 40 to 150 amu on the third collector.

2.0

EXPERIMENT PURPOSE

Data from the mass spectrometer would be applicable in several areas of lunar study, such as in investigating the suggestion that noble gases, carbon dioxide, carbon monoxide, hydrogen sulfide, ammonia, sulphur dioxide and water vapor may be released by lunar volcanism and from rocks and magma. Argon would be a particularly significant gas to study because of its relationship to the K-Ar dating process. Also its isotopic composition would be of interest as the different isotopes have different origins or production mechanisms. Ar^{40} is formed by the decay of K^{40} ; Ar^{36} and Ar^{38} may be spallation products of cosmic ray interactions with surface materials. The mechanisms of release of gases from the surface, e.g. solar wind bombardment, perhaps can be affirmed knowing what the effluent gases are.

Likewise, data on released gases will certainly afford some knowledge of the chemical processes underlying the lunar surface. Location of areas of released gases are related to the selenological structures in these areas. Thus, the mass spectrometer could be used as a tool to locate areas of active volcanism on the moon.

Finally, the mass spectrometer will provide a means for determining the natural distributions of gases in the lunar atmosphere. This information is essential if the sources, sinks, and transport of these gases are to be understood. Since the lunar atmosphere is a classical example of an exosphere, its global structure can be used to test theories on exospheric transport, which is an important process in the terrestrial atmosphere.

It has recently been shown that light gases with negligible production and loss range tend to be distributed at the lunar surface as the inverse $5/2$ power of temperature, while heavier gases are influenced by rotation of the moon. Neon falls into the former category, and its concentration on the dark side should be about 10 times that on the sunlit side. Its scale heights on the dark side is about $1/4$ that on the sunlit side, and thus at an assumed satellite altitude of 30 km the diurnal fluctuation of neon concentration should be about 10. Argon, being heavier, is expected to be noticeably influenced by rotation of the moon, having slightly less diurnal variation than neon and a longitudinal shift of its maximum toward sunrise, resulting in a concentration at sunrise that is about 2 times that at sunset.

Other atmospheric gases are not as amenable to analytic analysis, but their distributions are nonetheless important. Hydrogen and helium, which are thought to originate mainly through neutralization of solar wind ions on the lunar surface, are produced mainly on the sunlit surface, escape easily, and thus are not expected to be concentrated excessively on the dark side. The accretion rates can be calculated assuming a direct impingement of the solar wind on the lunar surface, and assuming that the composition of the solar wind is the same as that for the solar surface. Both these assumptions and the process of accumulation and escape of these gases can be checked with the mass spectrometer data. A typical mass spectrum as obtained from the GALA is shown in Figure 2-1.

3.0 EQUIPMENT DESCRIPTION

3.1 The GALA consists of two basic subassemblies, (1) the mass spectrometer, and (2) the electronics unit to operate the spectrometer and to interface with the ALSEP system. The system functional block diagram is shown in Figure 3-1.

Figure 3-2 shows the complete instrument with the mass spectrometer in the lower section and the electronics in the upper section.

3.1.2 Mass Spectrometer

The mass spectrometer consists of two filaments, an ionization chamber, focusing grids and plates, and three separate ion paths with electron multipliers. One magnet is used for the three channels. The mass spectrometer is constructed of stainless

steel and will be vacuum sealed for flight units. A squib operated opener will be used to expose the unit to the atmosphere to be analyzed. Figure 3-3 and 3-4 show the basic mass spectrometer.

3.1.3 Electronics

The electronics unit consists of the following 12 subassemblies and a interconnecting wiring board:

- (1) Pre-regulator,
- (2) Low voltage power supply,
- (3) High voltage power supply,
- (4) Emission control power supply,
- (5) Temperature control and squib firing,
- (6) Digital sweep,
- (7) Counting and data compression (Channel 1),
- (8) " " " " (" 2),
- (9) " " " " (" 3),
- (10) Data control and signal conditioning,
- (11) Housekeeping and output register,
- (12) Analog to digital converter.

3.1.3.1 Pre-Regulator

The voltage pre-regulator is a switching type regulator which converts the 29 volt spacecraft power to a regulated 20 volt output. The module also contains a current sensing circuit for monitoring the current drawn from the +29 volt line.

3.1.3.2 Low Voltage Power Supply

The low voltage power supply operates from the pre-regulated 20 volt supply and provides the following output voltages.

- (a) -25V dc unregulated
- (b) +15V dc unregulated

- (c) +12V dc
- (d) -12V dc
- (e) -7.5V dc
- (f) -16V dc
- (g) + 5V dc

All of the low voltage power supply regulators are the series type.

3.1.3.3 High Voltage Power Supply

The high voltage power supply has two outputs as shown below.

- (A) 3000V dc,
- (B) 300 - 1200V dc.

The 3000V dc is used to power the three electron multipliers and the 300 - 1200V dc is used to sweep the ion source of the mass spectrometer.

3.1.3.4 Emission Control Power Supply

The emission control power supply provides the circuitry to drive the filaments and all of the electrodes of the mass spectrometer ion source. This supply is floating at the voltage level of the high voltage sweep supply.

3.1.3.5 Temperature Control and Squib Firing

The temperature control and squib firing module provides the circuitry for the following purposes.

- (A) Monitor the package temperature and control the heaters,
- (B) Monitor the mass spectrometer temperature,
- (C) Accept commands and control the squib firing for the mass spectrometer cover and the dust cover removal.

3.1.3.6 Digital Sweep

The digital sweep generator contains a counter and ladder network to provide an analog signal to drive the high voltage output card. The step voltages for the mass spectrometer are established by the counter and gate function in the sweep generator.

3.1.3.7 Counting and Data Compression

Three identical counting and data compression modules are used, one for each mass range.

This module contains the pre-amplifier which amplifies and shapes the signal received from the electron multiplier in the mass spectrometer. The shaped pulse is then counted in a 21-bit counter. The module also contains a compression circuit to compress the counter data to 10 bits to comply with the 10-bit words used in ALSEP. This module also contains the shift register for transferring data to the ALSEP.

3.1.3.8 Data Control and Signal Conditioning

The data control and signal conditioning module contains most of the interface circuitry between the experiment and the ALSEP central station.

3.1.3.9 Housekeeping and Output Register

The housekeeping multiplexer and output register module contains the circuitry for multiplexing the various experiment housekeeping parameters and providing an analog output of the parameters to the analog and digital converter.

3.1.3.10 Analog to Digital Converter

The analog to digital converter converts the housekeeping parameters to digital form suitable for acceptance by the ALSEP central station.

3.1.3.11 Temperature Sensors

Two temperature outputs are provided. One indicates electronics package temperature and the other indicates the mass spectrometer temperature.

4.0 DATA FORMAT

The GALA experiment used five (5) ten (10)-bit digital words each frame period. The format for the 3 data words is shown in Fig. 4-1. The data words are ALSEP words 19, 21, and 49. The housekeeping word format is shown in Fig. 4-2, and is ALSEP word 5. The sub-commutated data assignments for the housekeeping word are shown in Fig. 4-3. ALSEP word 14 is used as the flag word for GALA. The format for the flag word is shown in Fig. 4-4.

5.0 COMMANDS

The GALA command code is shown in Fig. 5-1.

6.0 ELECTRICAL INTERFACE

The GALA Cable-Pin Assignment is as shown in Fig. 6-1.

7.0 ENVIRONMENTAL SPECIFICATIONS

The GALA environmental test specification is included as Appendix B of "High-Sensitivity Magnetic Sector Mass Spectrometer for the ALSEP Program," dated 3 June 1970.

8.0 GROUND SUPPORT EQUIPMENT

The GSE description is found in Section III-B of the report referenced in Paragraph 7.0, above.

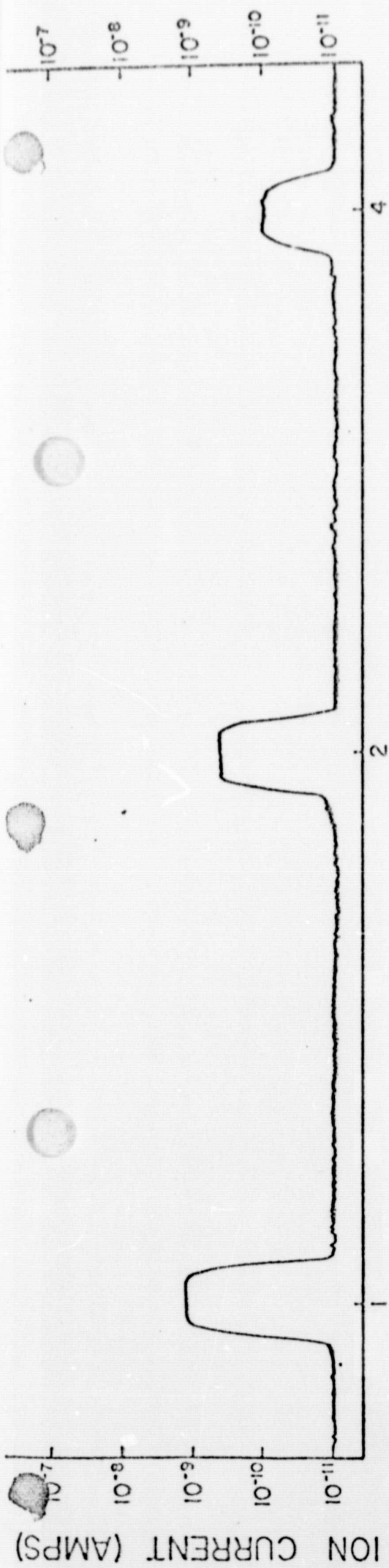
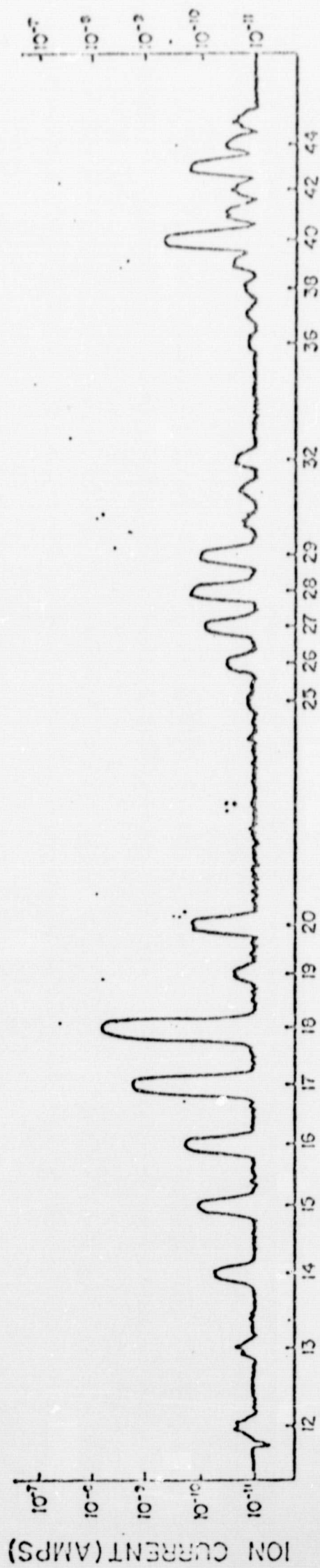
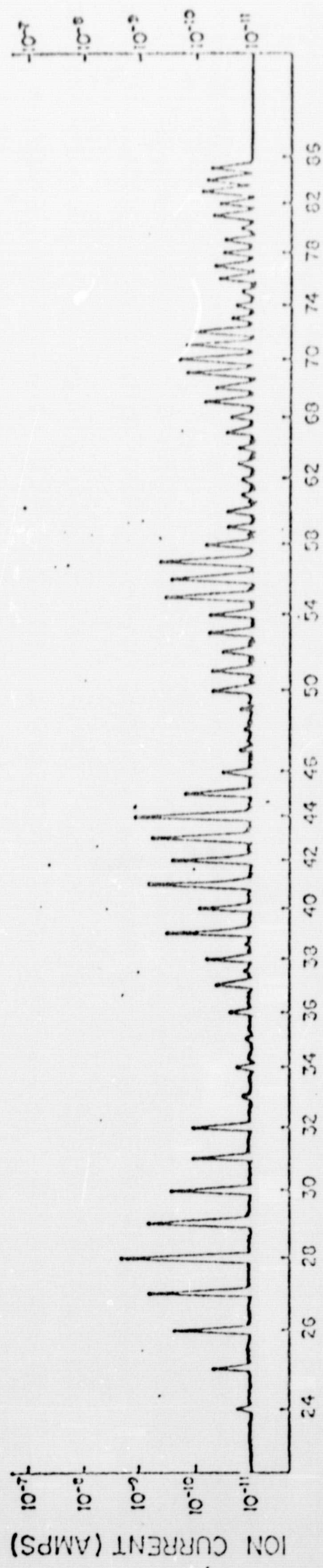
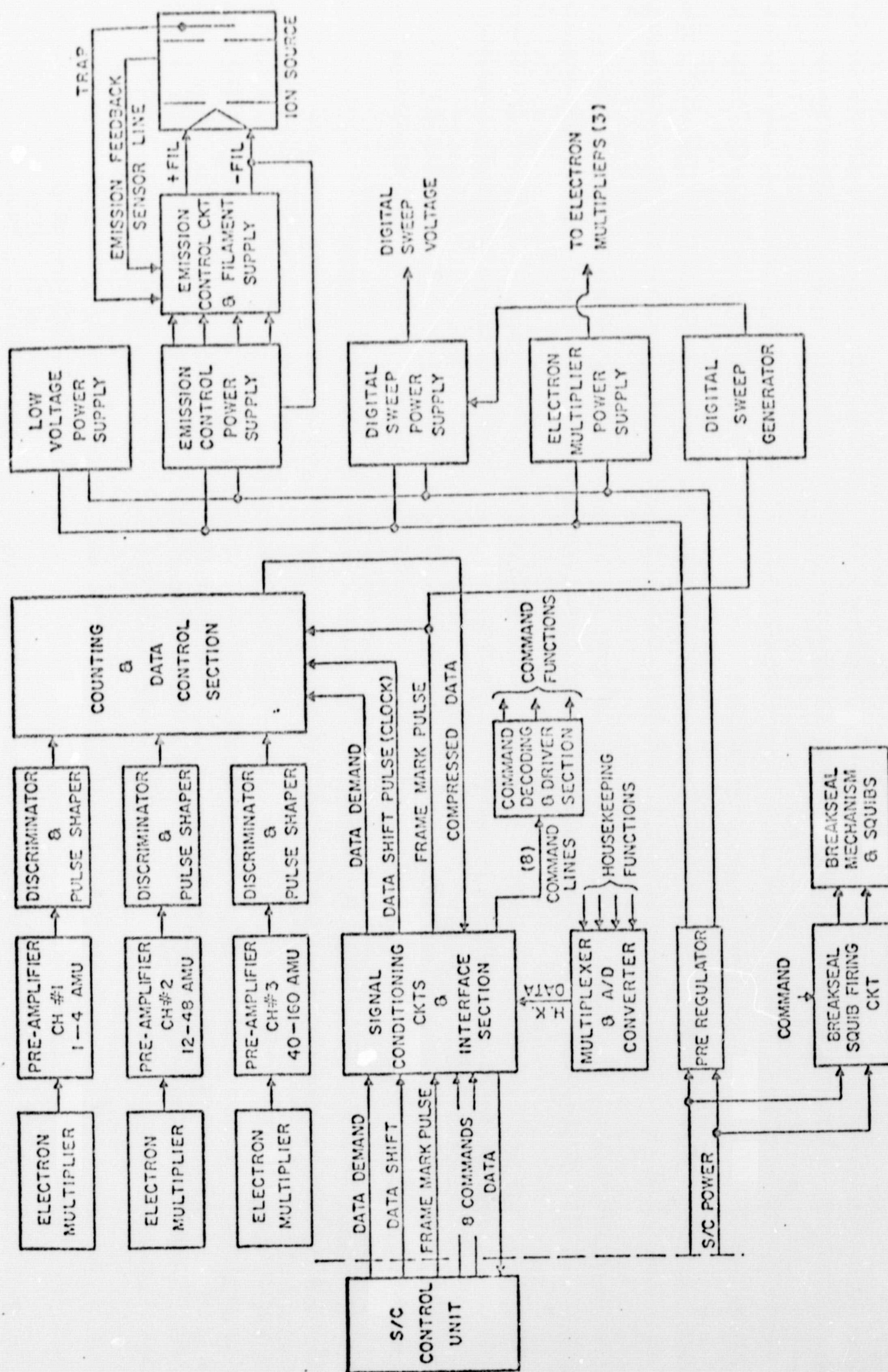


Figure 2-1. Mass Spectra Ranges



ALSEP
LUNAR MASS SPECTROMETER
FUNCTIONAL BLOCK DIAGRAM

Figure 3-1

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR.

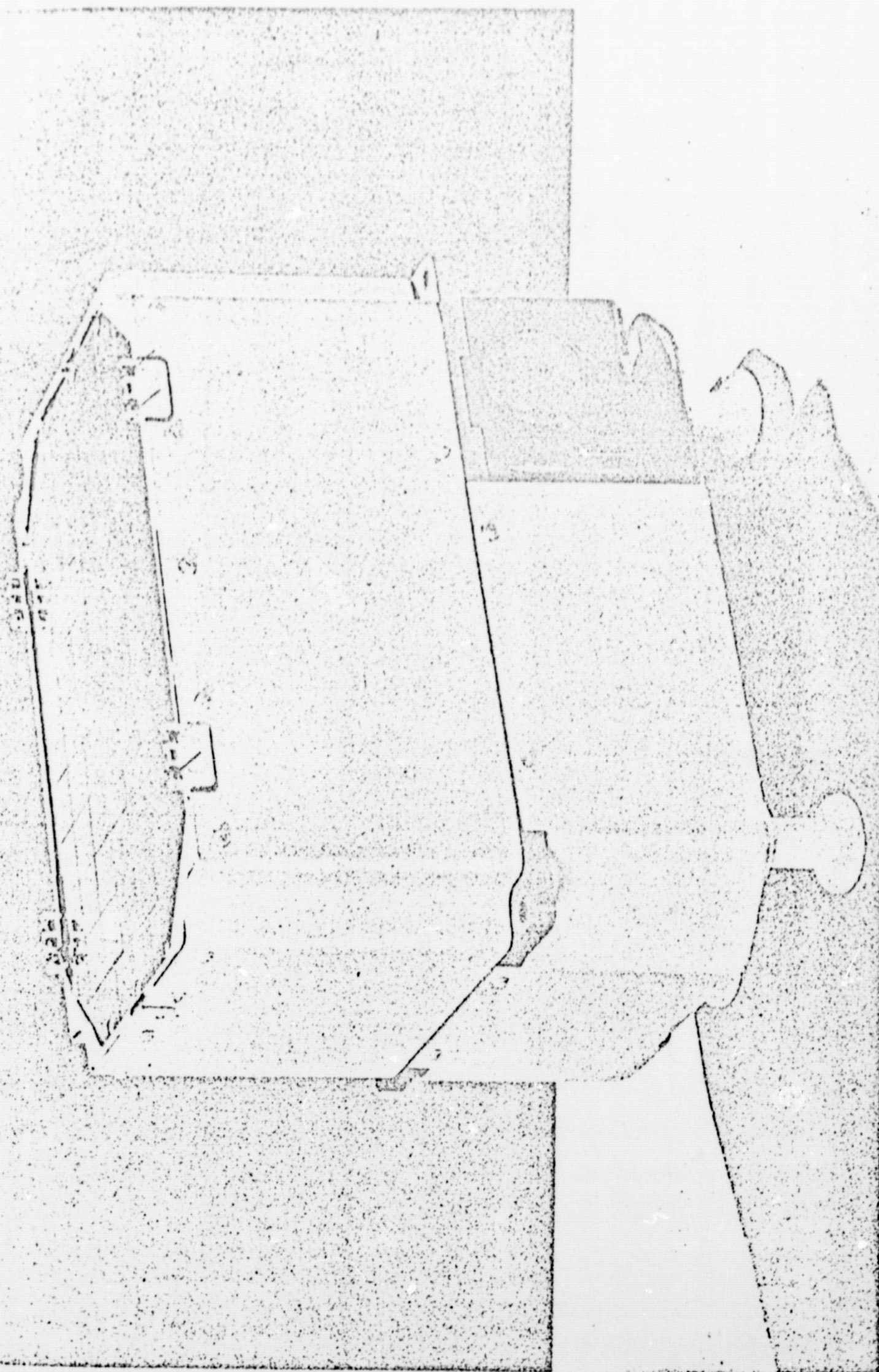


Figure 3-2. Mass Spectrometer

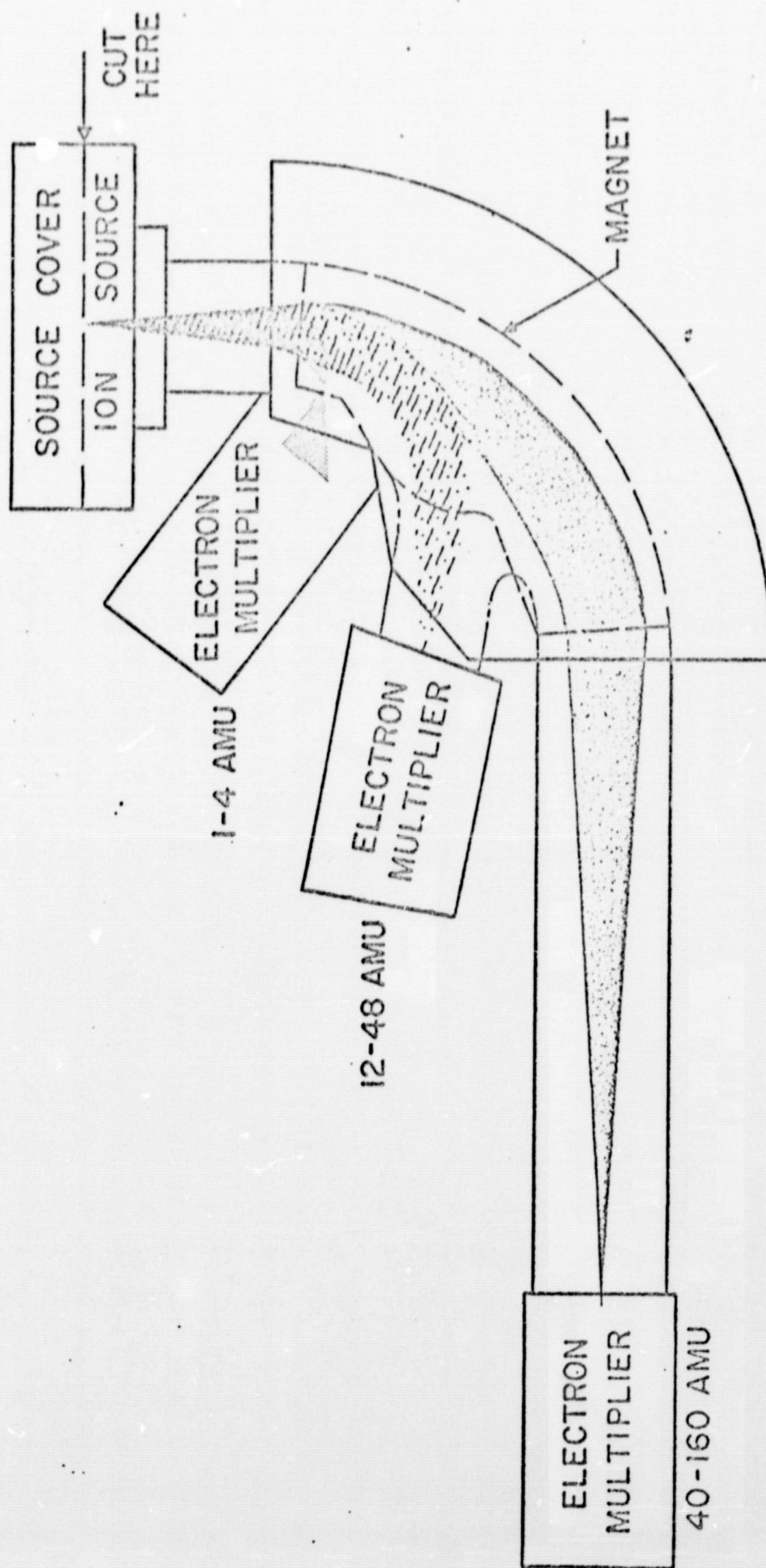


Figure 3-3. Mass Spectrometer Component Layout Diagram

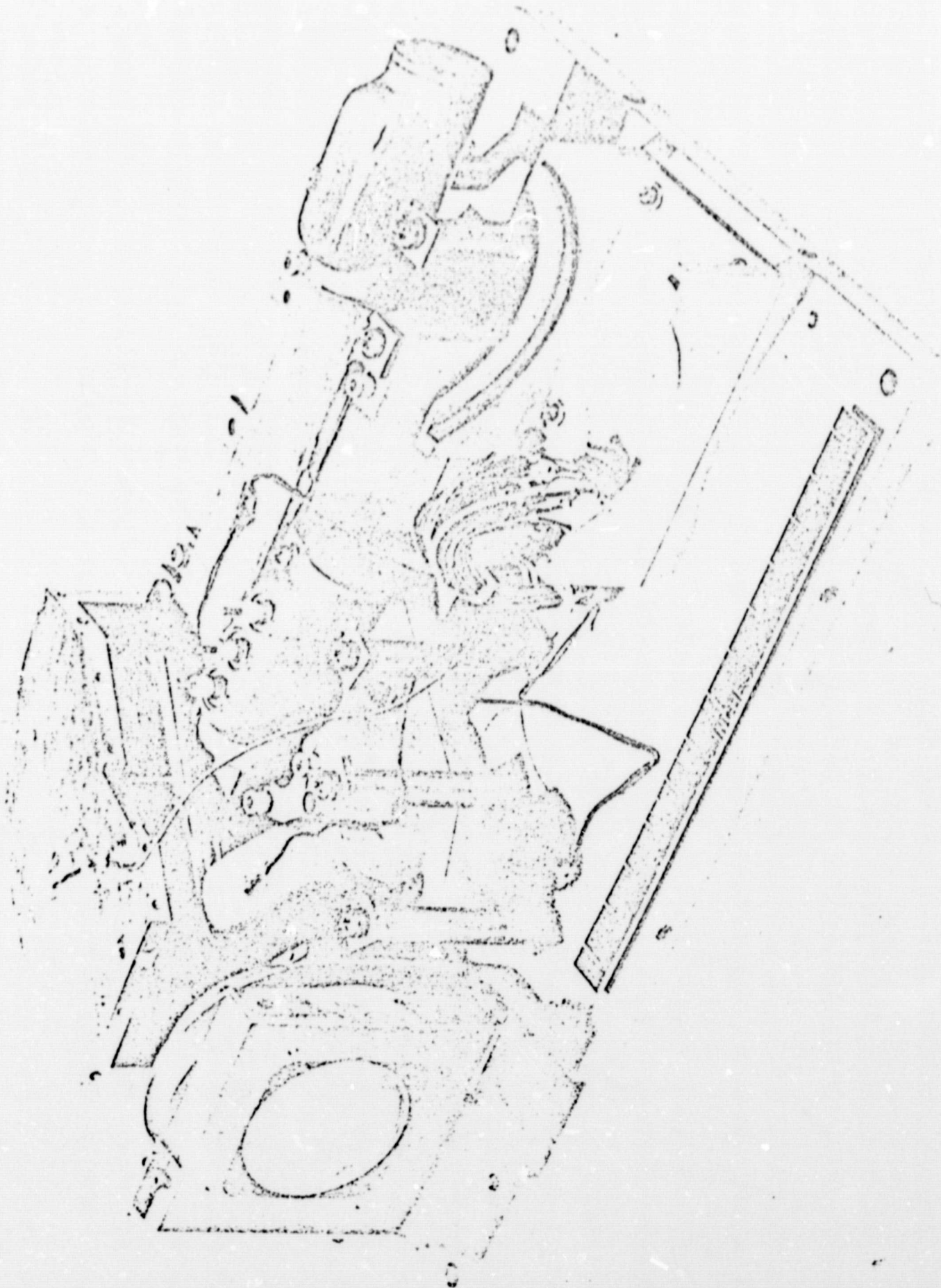


Figure 3-4. Mass Spectrometer Details

GALA DATA WORD

DATE 9 APR 69
HF

$S = \text{No. SHIFT PULSES}$

$D = \text{THE SIX MOST SIGNIFICANT BITS}$

$$\begin{aligned} \text{NUMBER COUNTS} &= (D+64)(2^{14-S}) && \text{WHEN } S \leq 14 \\ &= D && \text{WHEN } S = 15 \end{aligned}$$

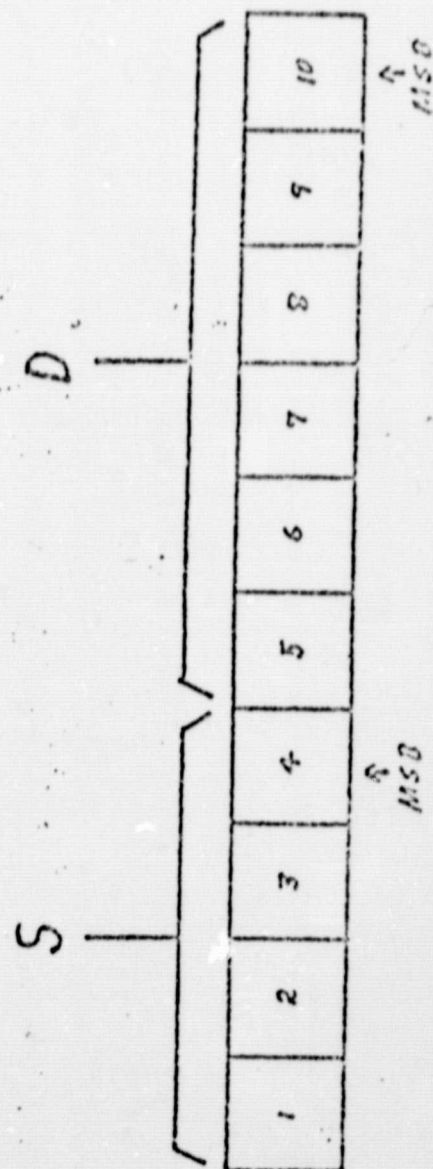


FIG 4-1

DATE 9 APR 69
HH

GALA HOUSEKEEPING WORD

(DATA DEMAND WORD 5)

HOUSEKEEPING DIGITAL WORD
DIGITAL SWEEP START FLAG
HOUSEKEEPING MULTIPLEXER POSITION #1 F

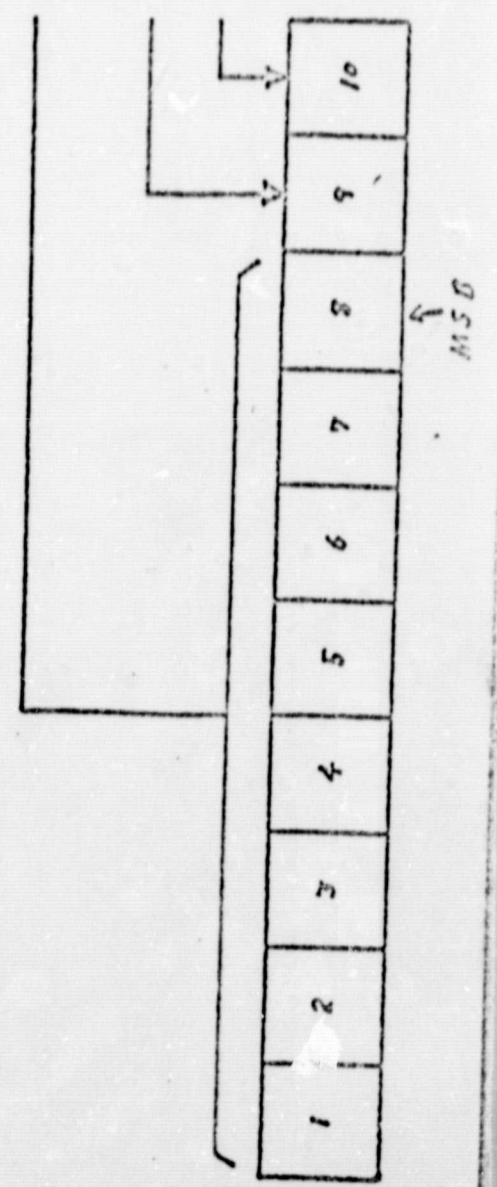


FIG 9-2

GALA

SUB-COMMUTATED HOUSEKEEPING DATA ASSIGNMENTS

<u>DATA NUMBER</u>	<u>H.K. DATA</u>
1.	-12V
2.	+ 5V
3.	+12V
4.	Spare
5.	A/D Calibrate
6.	Filament Current
7.	Instrument Current
8.	H. V. Mult. Monitor
9.	H. V. Sweep Monitor
10.	Temp. #1 (Electronics)
11.	Temp. #2 (M.S.)
12.	Spare
13.	Flags
14.	Spare
15.	-16V Ref.

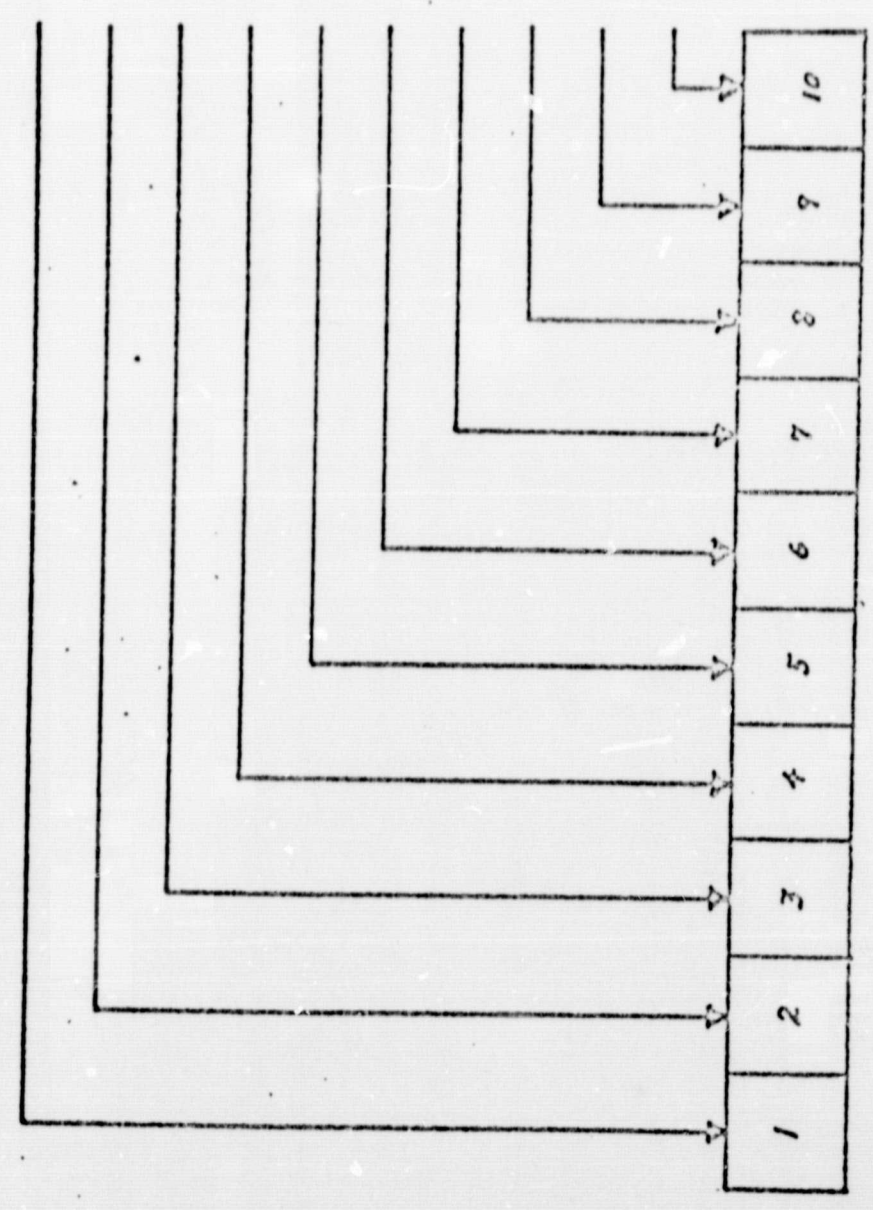
DATE 9 APR 69

GALA FLAG WORD

(HOUSEKEEPING WORD #14)
ALSEP WORD #14

BINARY '1' REPRESENTS

- MULTIPLIER GAIN #1
- MULTIPLIER GAIN #2
- SPARE
- EMISSION ON
- EMISSION HIGH
- FILAMENT #1
- DISCRIMINATOR HIGH
- SPARE
- DIGITAL SWEEP START
- HOUSEKEEPING MULTIPLEXER POSITION 1



GALA COMMAND CODE

<u>Command #</u>	<u>Command Generated</u>
1 & 2	Survival
1 & 3	Operate
1 & 4	Discriminator Hi
1 & 5	Discriminator Lo
2 & 3	Filament #1
2 & 4	Filament #2
2 & 5	Multiplier Hi
3 & 4	Emission Off
3 & 5	Emission On
4 & 5	Multiplier Lo
6	Command Clear
7	Break Seal
8	Dust Cover

GALA CABLE-PIN ASSIGNMENTS

<u>Pin #</u>	<u>Function</u>	<u>Pin #</u>	<u>Function</u>
1	Shield	17	Command #8
2	Data Line	18	Data Return
3	Shield	19	Chassis Return
4	Frame Mark	20	Power Return
5	Shield	21	Operate Power
6	Data Shift Line	22	Power Return
7	Shield	23	Operate Power
8	Data Demand Line	24	Power Return
9	Shield	25	Operate Power
10	Command #1	26	Power Return
11	Command #2	27	Operate Power
12	Command #3	28	Not Used-Spare
13	Command #4	29	Not Used-Spare
14	Command #5	30	Not Used-Spare
15	Command #6	31	No Connection
16	Command #7	32	No Connection

Shield connected at central processing unit.

Connector - Deutch - DTK06-18-32PW-059.

Above data from magnetometer integration doc.